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ARMY AVIATION ENGINEERING FLIGHT ACTIVITY EDWARDS AFB
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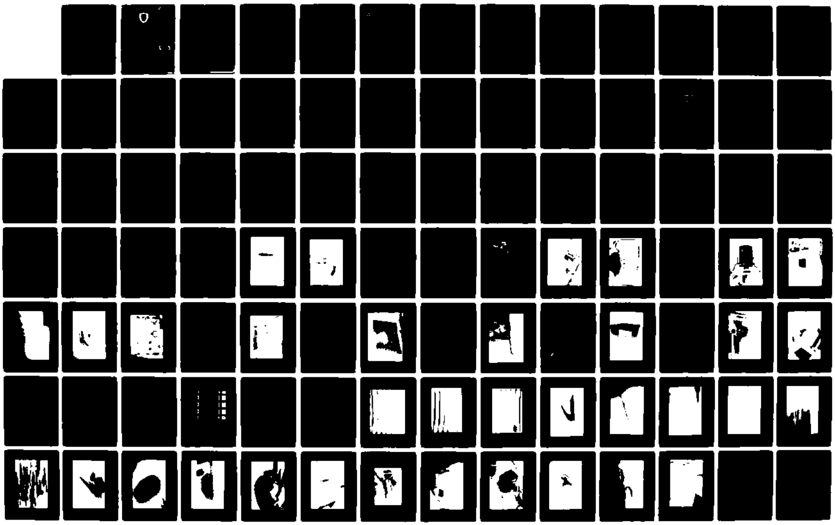

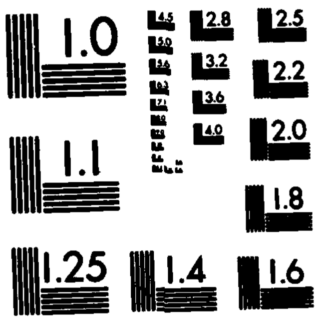

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USAAEFA PROJECT NO. 79-07

ARTIFICIAL AND NATURAL ICING TEST OF THE YCH-47D

FINAL REPORT

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Natural Icing Evaluation	Deice System Functioning
Boeing Vertol	Anti-ice Systems for Engines, Engine
CH-47D	Air Induction Systems, Windshields
Fiberglass Rotor Blades	Heater Outlet Icing
Full Tank Vent Icing	Electrothermal Rotor Blade Protection

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The YCH-47D helicopter icing test was conducted between 4 February and 28 March 1980. Twenty flights were conducted, seven in the artificial environment, eleven in natural icing and two flights in heavy snow. A total of 35 hours were flown with 17.4 hours in the icing environment. Testing was conducted at St Paul, Minnesota, in two phases: (1) protected (the deice system operated automatically) in the artificial environment and (2) unprotected (the deice system in a standby status), both in the artificial and natural environment. The YCH-47D was evaluated at conditions varying from 0.1 to 1.5 gm/m^3 liquid water content (LWC) and temperatures varying from -2°C to -20°C. Maximum time for an individual flight in the natural environment was 95 minutes at an average LWC of 0.2 gm/m^3 and -10°C. All tests, except the first, were conducted with an average

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) starting gross weight of 47,700 pounds. The YCH-47D, with unheated rotor blades, can operate continuously at temperatures to -5°C with up to 0.5 gm/m^3 LWC without incurring significant blade damage or asymmetric shedding. The risk of blade damage and asymmetric shedding increases significantly at lower temperatures and higher LWC. To fly in the icing environment, a reliable cockpit indication of the icing environment is necessary. The aft droop stop cover, fuel vent screens and modified cabin heater drain, which were design changes for previously identified problem areas, performed satisfactorily under all conditions tested. The two deficiencies identified during unheated blade operation were: (1) unacceptable lateral vibrations resulting from asymmetric rotor blade ice shedding at -19°C until the deice system was activated, at which time the excessive vibrations disappeared; and (2) rotor blade damage incurred from ice sheds at -10°C and 1.2 gm/m^3 LWC. Nine shortcomings were noted with three being ice related. Further testing to optimize the rotor blade deicing time, time between cycles, and determine an optimum location for an ice detector is necessary. Based on the test results, only a limited envelope should be considered for flights in icing conditions with unheated rotor blades.

DEPARTMENT OF THE ARMY
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SUBJECT: Directorate for Development and Qualification Position on the Report of USAAEFA Project No. 79-07 Artificial and Natural Icing Test of the YCH-47D

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1. The purpose of this letter is to establish the Directorate for Development and Qualification position on the subject report. The overall objective of the test program was to establish a flight envelope for the YCH-47D for flight in icing conditions. Based on the results of flight testing, the YCH-47D exhibited the capability for flight into light icing conditions to $-5^{\circ}C$ without incurring blade damage from asymmetric ice shedding. Below $-5^{\circ}C$ and at up to $.5 gm/m^3$ liquid water content (LWC) blade damage will occur resulting from shed ice impact damage. While this does not limit the capability of the YCH-47D to fly under light icing condition released for the CH-47C helicopter, it will result in significant maintenance problems. Consequently, it is not recommended that the CH-47D be flown in light icing conditions at less than $-5^{\circ}C$. If it is, then appropriate warnings need to be incorporated into the Operator's Manual. Additionally, a LWC meter becomes necessary to insure that if icing encounters of greater than light severity are met, they can be identified and necessary action taken to vacate the icing environment.

2. This Directorate agrees with the conclusions and recommendations except as indicated below. Additional comments are provided relative to the report and are directed to the report paragraphs as indicated.

a. Paragraphs 4, 6, and 7. The first objective of the YCH-47D test program was to establish a flight envelope to operate continuously in light icing conditions and for 30 minutes in moderate icing conditions, without heated blade protection. The second objective was to determine the feasibility of establishing a flight envelope for the aircraft, with heated blades, to operate in icing conditions beyond the capability of the unheated blade. Since no firm requirement existed to provide ice protection beyond the 30 minute moderate icing encounter only three flights were conducted with heated blades. These heated blade tests were conducted to verify proper operation of the de-ice systems prior to flight in the natural environment. Heated blades were to be used thereafter only as a backup during unheated blade testing.

b. Paragraph 51a. The YCH-47D with unheated rotor blades could operate continuously in light icing conditions to temperatures down to -5°C. Light icing conditions are defined as those with liquid water contents (LWC) from .15 to $.5 gm/m^3$ and temperatures from 0°C to -20°C. Continuous operation in the entire light icing environment was not demonstrated during testing. Two severe asymmetric sheds occurred during two separate artificial icing test flights at

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-19°C and at LWC of $.6gm/m^3$. Although slightly above the $.5gm/m^3$ limit of LWC for light icing, these were the only flights conducted at low temperatures. The coldest natural icing flight was conducted at -13°C with a LWC of $.2gm/m^3$. The highest LWC encountered during a natural icing flight was $.6gm/m^3$ at a temperature of -3°C. No problems in the form of asymmetric sheds (moderate or severe vibrations) occurred during these two tests, or any other natural icing test flights. The inability of the YCH-47D to operate continuously in the entire light icing envelope was demonstrated by problems which occurred during artificial icing tests. Since no natural icing flights were conducted at low temperatures and LWC of $.5gm/m^3$, it is still possible that a full light icing envelope may exist for the aircraft.

c. <u>Paragraph 51b</u>. Significant forward and aft rotor blade damage, due to ice shedding, occurred during both artificial and natural icing tests. Aft rotor blade damage can be expected on tandem rotor aircraft; it is significant to note that damage occurred to the forward rotor blade as well. Blade damage occurred in a natural icing flight with an LWC of only $.1gm/m^3$. Although only three flights were flown with heated blades, no blade damage occurred during these flights. Blade de-ice systems are usually designed to allow ¼ inch to ½ inch of ice build-up at midspan, before shedding occurs. Pieces of ice as thick as 3/4 inch were observed and measured on unheated blades during testing. The large amount of rotor blade damage that occurred is due to the greater thickness of ice that forms on unheated blades before self-shedding occurs.

d. <u>Paragraph 51c</u>. In order to clear an aircraft for a partial icing envelope an accurate cockpit display of the environment, in terms of outside air temperature and LWC, must be installed. This is necessary to warn the pilot that he may be entering a condition more severe than that for which his aircraft has been cleared. Unaspirated ice detectors, because of calibration errors over the airspeed range, are less satisfactory than the aspirated types. An LWC meter display from 0 to $2.0gm/m^3$, over a needle sweep of 270°, has been found to be preferred. Proper location of an ice detector for the CH-47D requires further evaluation.

e. <u>Paragraph 51f</u>. Testing indicated that continuous flight in light icing conditions to -15°C can be accomplished with engine anti-ice off, without incurring engine damage. Full qualification of the CH-47D, with engine anti-icing off, requires more testing; also qualification to a partial icing envelope requires adequate display of OAT and LWC.

f. <u>Paragraph 52a</u>. The unacceptable 1 per revolution lateral vibration resulting from asymmetric rotor blade ice shedding occurred at a LWC of $.6gm/m^3$ and -19°C which is outside the light icing envelope. Additionally, this occurred on the unheated blades and consequently is not a deficiency for a light icing envelope.

g. <u>Paragraph 52b</u>. The rotor blade damage incurred from the ice shed at -10°C and a LWC of $1.2gm/m^3$ represents heavy icing conditions well outside a light envelope as well as moderate icing envelope. Consequently, this is not a deficiency for flight into a light icing envelope.

h. Paragraph 53a. The erratic operation of the combining transmission oil pressure gage caused by ice accretion on the oil pressure transmitter electrical connector is a shortcoming which will be corrected in production. To correct the shortcoming, a metal back shell will be installed to prevent ice formation directly on the connector as well as to prevent water from running down the wires when melting occurs.

i. Paragraph 53b. The water leaking into the cockpit through overhead console is a shortcoming that will be corrected on production CH-47D's by improving cockpit sealings. Rain test techniques have also been improved to verify the improved sealing.

j. Paragraph 53c. Intermittent operation of Leigh Mark XII ice detector can be due to many causes. The variable droplet sizes and flow rates delivered by the HISS could be the chief cause. Ludlam limit problems, occurring near 0°C can also cause intermittent operation. Inasmuch as the Leigh is not a standard installation on the CH-47D its intermittent operation is not considered a shortcoming.

k. Paragraph 54a. Aircraft rigging techniques have been revised to reduce the unsatisfactory power management characteristics of the T55-L-712 engine at low power setting. These techniques will be incorporated in production.

l. Paragraph 54b. Tuning range of the absorbers will be changed on the production CH-47D to reduce vibration levels.

m. Paragraph 54c. Factory tools and bending angle measurement procedures have been improved to maintain preset trim angle and eliminate the inability of the blade trim tab to retain the preset deflection.

n. Paragraph 54d. Support structure has been beefed-up on production models to eliminate cracks of the number 1 hydraulic power control module supports.

o. Paragraph 54e. A solution to the oscillating localizer needle on the course deviation indicator problem was found during a test program concluded recently at Ft Rucker. A ram's horn type antenna located underneath the fuselage reduced the oscillations to an acceptable level.

p. Paragraph 54f. Currently, correction of the insufficient volume in the interphone set is not possible. Increasing the volume level of the C6533 to compensate for the use of ear plugs will not improve the speech intelligibility of the intercommunication system. Increasing the volume level also increases the noise level and the distortion further aggravating the problem. The new intercommunication system, C10414 has an increased signal to noise ratio

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improving speech intelligibility. This intercom system is new and it is not known at this time when a PIP will incorporate it into the CH-47 fleet.

3. As a result of the icing test, the YCH-47D with unheated rotor blades demonstrated the capability to operate continuously in light icing to -5°C without resulting blade damage from shed ice. Below -5°C blade damage from shed ice can be expected with the potential for damage increasing with decreased temperature and increased LWC. As a result of the preceding the CH-47D is qualified for flight into light icing conditions and the following should be included in the Operator's Manual, "The helicopter is equipped with adequate engine anti-icing, pitot tube and Advanced Flight Control Systems (AFCS) yaw port heating, and windshield anti-icing system to enable safe flight in light icing conditions. Continuous flight in light icing conditions below -5°C is not recommended since blade damage can occur from asymmetric ice shedding."

4. Because of the potential for blade damage from shed ice in light icing conditions, it is recommended that a rotor blade ice protection system be incorporated. Incorporation of a system, as demonstrated during the icing tests, would also allow expanding the CH-47D capability to include flight into moderate icing conditions.

FOR THE COMMANDER:

CHARLES C. CRAWFORD, JR.
Director of Development
and Qualification

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APPENDIXES

INTRODUCTION

BACKGROUND

1. The US Army Aviation Research and Development Command (AVRADCOM) has contracted with the Boeing Vertol Company (BV) to design, fabricate, test and qualify the YCH-47D with fiberglass rotor blades (FRB). The YCH-47D incorporates a BV designed test deicing system. Limited testing with this system was conducted on the CH-47C with FRB and a "breadboard" deicing system during the winter of 1978/79 (ref 1, app A). This testing was conducted in an artificial icing environment using the helicopter icing spray system (HISS) (App B). Additional testing was conducted in natural icing conditions with unheated FRB.

2. Results from previous testing indicated that the HISS did not produce an accurate simulation of the natural icing environmont (ref 2, app A). The HISS was modified to produce realistic cloud characteristics at low liquid water contents (LWC). Calibration of the cloud confirmed that the droplet size and distribution were both improved to produce a cloud more representative of natural conditions.

3. In September 1979, AVRADCOM tasked the US Army Aviation Engineering Flight Activity (USAAEFA) to plan, test and report on the capability of the YCH-47D to operate in icing environments (ref 3, app A).

TEST OBJECTIVES

4. The objectives of this test program were:

a. Collect data to determine the feasibility of establishing a flight envelope allowing the YCH-47D to operate continuously in light icing conditions and for 30 minutes in moderate intensity icing conditions without heated blade deice protection.

b. Collect data to determine the feasibility of establishing a flight envelope for the YCH-47D, with heated blades to operate in icing conditions beyond the capability of the unheated blade.

c. Determine the effectiveness of the ice detection and ice accretion rate systems to provide adequate cockpit indications for safe operation under icing conditions. Address the usefulness of at least the following:

(1) Leigh Mark XII LWC display

(2) Production free air temperature (FAT) probe

(3) Windshield wipers

(4) Other existing protuberances

d. Evaluate the effectiveness of the modifications applied to correct the problem areas encountered during prior tests (ice blockage of the fuel vents and heater drain and the failure of the centrifugal droop stops to retract after ice accumulation).

DESCRIPTION

5. The YCH-47D helicopter is a modernized version of the Army CH-47 tandem-rotor, twin engine helicopter manufactured by BV. The test aircraft (S/N 76-8008) was a prototype YCH-47D helicopter equipped with production fiberglass rotor blades modified to incorporate heater blankets, an auxiliary 40 kilovolt amps (KVA) generator mounted on the aft transmission, a test blade deice control system and an instrumentation package. Equipment modifications incorporated as a result of previous test results were: droop stop covers, conical screens around the fuel vents and cabin heater drain tube redesign. A detailed description of the aircraft and deice system may be found in the operator's manual (ref 4, app A) and appendix B. A description of the HISS is also in appendix B.

TEST SCOPE

6. The YCH-47D icing tests were conducted in St. Paul, Minnesota from 4 February 1980 through 28 March 1980 by a joint USAAEFA and BV team. Twenty flights for a total of 35 hours were flown with 17.4 hours in the icing environment. Three flights with heated rotor blades were conducted in the artificial icing environment (3.0 hours). Fifteen flights were conducted with unheated rotor blades: eleven flights in natural icing (12.0 hours), and four flights in the artificial environment (2.4 hours). Two flights were conducted in heavy snow (1.7 hours). Artificial icing tests at approximately 0.3 gm/m^3 LWC at -12°C and at 0.5 gm/m^3 LWC at -13°C and -20°C were used to verify proper operation of the deice system prior to flights in the natural environment. Tests with unheated rotor blades were conducted in natural icing conditions varying from 0.1 to 0.6 gm/m^3 LWC and temperatures from -2°C to -13°C, and artificial icing conditions varying from 0.7 to 1.5 gm/m^3 flow calibrated LWC and temperatures from -5°C to -19°C. The first icing test was accomplished at an engine start gross weight (ESGW) of 34,030 pounds and forward center of gravity (cg) of FS 328. Subsequent tests were conducted at ESGW between 47,300 to 47,800 pounds and cg's from FS 327 to 333. Pressure altitudes ranged from 1600 to 8500 feet with true airspeeds of 63 to 136 knots, and a rotor speed of 225 rpm.

7. BV installed the instrumentation on the test aircraft, provided instrumentation, maintenance support, and a copilot and flight test engineer. Flight limitations contained in the operator's manual and the airworthiness release (ref 5, app A) were observed throughout the test.

TEST METHODOLOGY

8. The test was conducted in two phases:

a. The first phase was conducted with heated rotor blades in the artificial icing environment behind the HISS: first, to verify proper operation of the heated rotor blade deice system and second, to insure that thick accumulations of blade ice could be removed in the event of an asymmetric shed. Ice accretion with the "fixes" for problem areas noted during previous tests and on the transmission cooler inlets were also evaluated in known conditions of temperature and LWC.

b. The second phase consisted of flights in artificial and natural icing conditions with unheated rotor blades. The effects of total aircraft immersion were examined with standard windscreen, pitot tube, stability augmentation system (SAS) port anti-ice and the number one engine anti-ice systems activated.

9. During flights in the artificial environment, the test aircraft was positioned in the HISS spray cloud approximately 150 feet behind the spray boom. Only one rotor at a time could be immersed in the cloud due to the depth of the HISS plume. The test aircraft was photographed to determine the ice accretion characteristics during the subsequent immersions. Immersion times were based on system operation and duration of HISS water supply.

10. Flights in the natural environment were made at an altitude that produced the greatest LWC within the cloud mass.

11. Cloud data was monitored in the cockpit by a Leigh Mark XII ice detector. The indicated values were also recorded on magnetic tape. Two Rosemount nonaspirated ice detectors were also installed and either could be selected to control the operation of the blade deice system. A complete description of the instrumentation is presented in appendix C.

12. Test techniques and data analysis methods are presented in appendix D. The method used to determine cloud parameters, definitions of icing types/intensities, and a vibration rating scale (VRS) are also presented in appendix D.

RESULTS AND DISCUSSION

GENERAL

13. The YCH-47D with rotor blade deice protection was tested in two phases: (1) heated, in the artificial environment and (2) unheated, both in artificial and natural icing conditions. Flights 1 through 3 were conducted behind the HISS to insure proper operation of the rotor blade deice system in the heated mode and, should an asymmetric shed occur, that large ice buildups on the remaining blades could be removed. A summary of all test conditions is shown in table 1. The LWC's were average values for flights in natural conditions while values recorded in the artificial environment were based on the flow rate calibration of the HISS. Flight time in the icing environment varied from 18 minutes to 95 minutes. All tests, excluding the first flight, were conducted with an ESGW of approximately 47,700 pounds. The unprotected rotor blades operated continuously down to -5° C and up to 0.5 gm/m^3 LWC without significant blade damage or asymmetric shedding. The risk of blade damage and asymetric shedding increases significantly at lower temperatures and higher LWC's. To operate in the icing environment the pilot must have a reliable cockpit indication of the icing level. Further testing to optimize the rotor blade deicing time, time between cycles, and to determine an optimum location for an ice detector is necessary. Modifications that were made to correct precisely identified ice-related problems with the aft droop stops, fuel vents, and cabin heater drain proved satisfactory during these tests (ref 1, app A).

14. Two icing related deficiencies with unheated blades and heavy gross weights were noted. The deficiencies are; (1) the unacceptable lateral vibration resulting from asymmetric rotor blade icing shedding at -19° C and 0.7 gm/m^3 LWC; (2) rotor blade damage resulting from ice impacts. Nine shortcomings were documented during this test with three being ice related. Based on the test results, only a limited envelope should be considered for flight in icing conditions with unheated rotor blades.

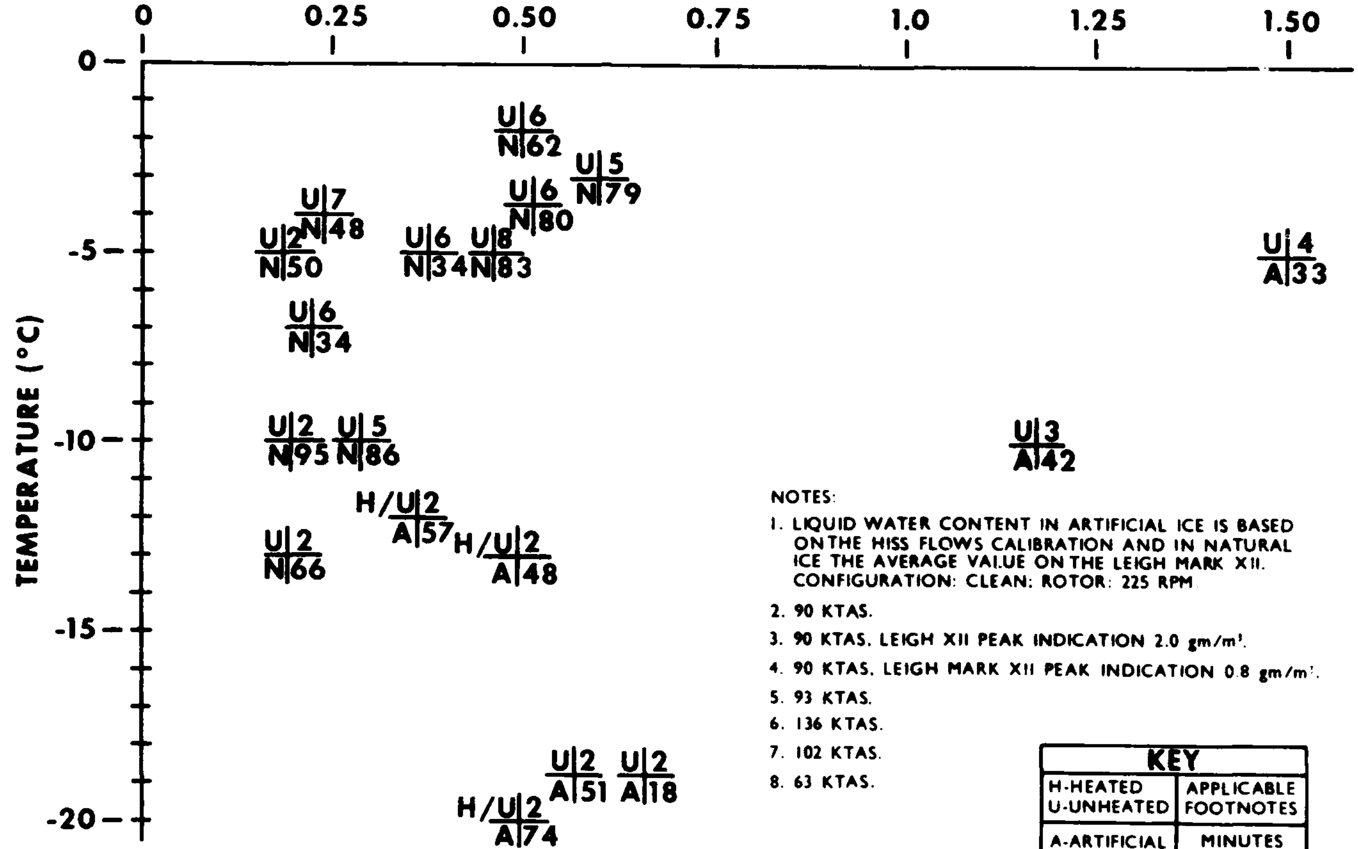
HEATED (PROTECTED) FIBERGLASS ROTOR BLADES IN ARTIFICIAL ICE

15. The YCH-47D with integral blade deice protection was evaluated during 3 flights at the conditions listed in table 2. The test techniques utilized for this test are described in appendix D. Tests of the heated FRB beyond the range of test conditions for the unheated blade were not conducted due to time constraints.

16. The first flight was conducted for comparison with previous test results at an engine start gross weith (ESGW) of 34,030, and for initial deice system checkout. During this flight ice accretion on an aft rotor blade to 2/3 span occurred after 15 minutes immersion in the HISS cloud. The time to the first deice cycle of the ice detector was 2 minutes and the maximum ice buildup on the airframe was 3/8 inch. These results compared favorably with those obtained during the CH-47C helicopter with fiberglass rotor blades icing test of 1979.

17. For all remaining tests the ESGW was approximately 47,700 pounds. The LWC was increased to 0.5 gm/m^3 and the temperatures on the 2nd and 3rd flights were -13° C and -20° C, respectively. Ice accreted on the full span of each rotor blade before the deice system was activated. No asymmetric ice sheds or unusual vibrations were noted during these tests.

TABLE 1. ICING TEST FLIGHT CONDITIONS



NOTES:

1. LIQUID WATER CONTENT IN ARTIFICIAL ICE IS BASED ON THE HISS FLOWS CALIBRATION AND IN NATURAL ICE THE AVERAGE VALUE ON THE LEIGH MARK XII. CONFIGURATION: CLEAN: ROTOR: 225 RPM
2. 90 KTAS.
3. 90 KTAS. LEIGH XII PEAK INDICATION 2.0 gm/m^3.
4. 90 KTAS. LEIGH MARK XII PEAK INDICATION 0.8 gm/m^3.
5. 93 KTAS.
6. 136 KTAS.
7. 102 KTAS.
8. 63 KTAS.

KEY	
H-HEATED U-UNHEATED	APPLICABLE FOOTNOTES
A-ARTIFICIAL N-NATURAL	MINUTES IN ICING CONDITION

Table 2. Heated Phase Rotor Blade Tests[1]

Flt	Date 1980	Ave Pressure Altitude (ft)	Ave OAT (°C)	Peak Indicated LWC[2] (gm/m³)	LWC From HISS Calibration (gm/m³)	HISS Flow Rate[3] (gal/min)	Relative Humidity (pct)	Deice Cycles	Immersion Times (min) Fwd Rotor	Immersion Times (min) Aft Rotor	Remarks
1	14 Feb	2150	-12	0.35	0.4	7	77	6	26	31	ESGW 34,030 lb cg FS 328 (fwd)
2	15 Feb	1600	-13	0.54	0.5	10	86	8	33	15	ESGW 47,300 lb cg FS 326 (fwd)
3	16 Feb	3040	-20	0.50	0.5	10	90	7	35	39	ESGW 47,700 lb cg FS 327 (fwd)
						Total time in cloud			1.6 hr	1.4 hr	

[1] Artificial Cloud; clean configuration; with rotor speed 225 rpm; average airspeed 90 KTAS
[2] Liquid water content as determined by the Leigh Mark XII Ice Detector
[3] Indicated flow rate

18. The deice system on-time was similar to that used for the 1979 icing test. The system, when activated to remove large ice buildups, operated satisfactorily. Attempts to optimize blade deice on-time and time between cycles were limited as the majority of the flight time was devoted to testing unheated blades. Within the scope of this test, the prototype rotor blade deice system provided excellent rotor blade protection. Based on the successful system operations during these three flights, a decision was made to proceed with tests in natural icing environments when the proper conditions were present. It should be noted that the prototype system's deice cycle length was set to the maximum permissible. Further testing is required to establish the optimum deice cycle time and time between cycles for best shedding with minimum power requirements or ice run back, for a production blade deice system.

UNHEATED (UNPROTECTED) FIBERGLASS ROTOR BLADES

General

19. The YCH-47D with unprotected fiberglass rotor blades was evaluated during 17 flights in the combination of natural and artificial icing conditions listed in table 3. Test techniques are described in appendix D. The rotor deice system was maintained in a standby mode and used only when an unacceptable asymmetric shed occurred.

20. The unheated rotor system was evaluated at conditions that varied from -2° C to -19° C with LWC values of 0.1 to 1.5 gm/m^3. Cloud immersion times varied from 18 minutes to 95 minutes. A high ESGW of 47,700 pounds was used to evaluate icing effects on rotor blades at an increased angle of attack which was assumed to be the more critical condition.

Natural Icing Environment

21. Natural icing conditions varied greatly in terms of LWC during any given flight. The nonhomogeneous nature of the cloud resulted in LWC's varying from a maximum of 0.69 to a minimum of 0.1 gm/m^3 on a single flight. Ice accumulations of up to 3 inches (76mm) after 66 minutes in natural ice were recorded on the vernier ice accretion meter (Harvey Smith). Flight times in icing conditions varied from 34 to 95 minutes. The coldest temperature encountered in the natural icing environment was -13° C with an average LWC of 0.2 gm/m^3. With the exception of a very mild one per revolution lateral oscillation, which occurred momentarily during flight 6 (table 3), there were no observable cockpit indications of accreted rotor blade ice or asymmetric shed characteristics.

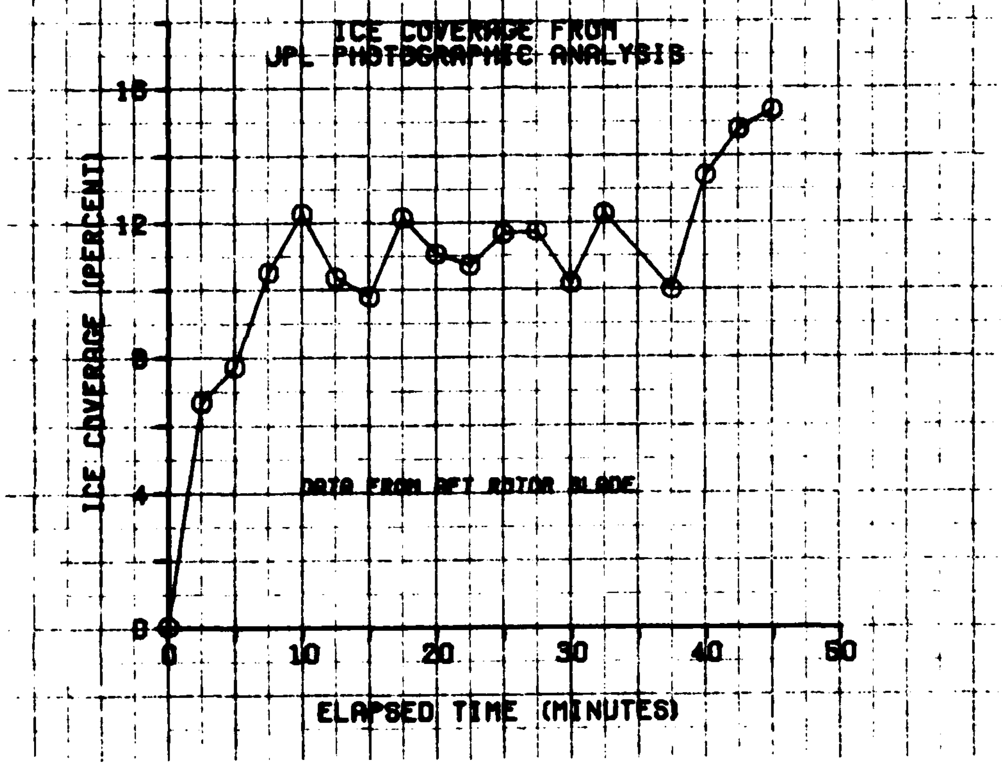
22. Ice accretion along the full span of the blade was documented on still and high speed motion photography. A camera mounted on the top of the cabin was synchronized with a single aft rotor blade. Pictures taken of flight 4, at 2-1/2 minute intervals, show the intermittent self shedding characteristics of the unheated FRB in natural icing conditions (photos 1-3, app E). The ice, depicted on the computer enhanced photographs, ends abruptly at 3/4 span of the blade and was not presented because of out of focus negatives. A computer analysis of the ice present on each blade is presented in figure 1. On flights 4 and 10, pieces of ice approximately 1 to 2 feet in length shed about blade station 180. Ice sheds were also noted in the vicinity of blade station 275. Thicker ice, as indicated by contrasting shades, was

Table 3. Unheated Phase Rotor Blades Test[1]

Flt	Date 1980	Ave Pressure Altitude (ft)	Ave OAT (C°)	Ave A/S (KTAS)	Icing Environment[2]	LWC[3] (gm/m³)	Flow Calibrated LWC[4] (gm/m³)	Ice Accretion Total (mm) Harvey Smith	Ice Accretion Ave Rate (mm/min) FWD Rose	Ice Accretion Ave Rate (mm/min) AFT Rose	Immersion Time (min) FWD Rotor	Immersion Time (min) AFT Rotor	Remarks[5]
4	23 Feb	4000	13	86	N	0.2	--	20	0.20	0.33	66	66	
5[6]	25 Feb	4200	-19	90	A	0.6	0.7	–	–	–	18		Relative humidity 40% Leigh Mark XII immersed 4 minutes in cloud
6	4 Mar	6000	-10	98	N	0.2	--	55	0.25	0.50	95	95	Small delamination underside fwd yellow blade In and out of cloud formation
8[7]	5 Mar	3000	-19	90	A	0.6	0.7	--	-	--	21	30	Relative humidity 68% Leigh Mark XII immersed 4 minutes in cloud.
9[8]	[illegible] Mar	2700	-10	90	A	2.0[9]	1.2	--	--	–	30	12	Large delamination underside aft green blade Relative humidity 78% Leigh Mark XII immersed 3 minutes in cloud.
10	12 Mar	8500	-5	90	N	0.1	--	28	0.25	0.39	50	50	Delamination underside aft yellow blade
12	23 Mar	5400	-5	90	A	0.8[9]	1.5	–	–	–	33	0	Relative humidity 63% Leigh Mark XII immersed 4 minutes in cloud
13	24 Mar	4000	10	93	N	0.2	--	42	0.20	0.50	86	86	
14	24 Mar	4000	-7	136	N	0.2	–	10	0.34	0.42	34	34	In and out of cloud formations
15	26 Mar	8000	-4	102	N	0.2	--	5	0.36	0.44	48	48	No. 1 engine anti-ice OFF
16	27 Mar	3500	-3	93	N	0.6	–	76	INOP	1.80	79	79	
17	27 Mar	3500	-2	136	N	0.5	–	70	2.30	1.80	62	62	
18	28 Mar	4500	-4	136	N	0.3	--	70	0.90	1.20	80	80	No. 1 engine anti-ice OFF
19	28 Mar	4500	-5	63	N	0.4	--	30	0.65	1.29	83	83	
20	28 Mar	4500	-5	136	N	0.4	--	40	0.83	1.02	34	34	
								Total Time in Cloud			13.7 hr	12.7 hr	
								Time in Natural Cloud			12.0 hr	12.0 hr	
								Time in Artificial Cloud			1.7 hr	0.7 hr	

[1] Clean configuration with rotor speed 225 rpm. All tests conducted with the blade deice in a standby mode. Average engine start gross weight 47,700 lb cg fs 327 (fwd).
[2] N = natural icing conditions, A = Artificial icing conditions (HISS).
[3] LWC = Liquid water content. As determined by Leigh Mark XII Ice Detector. Average LWC in natural conditions and peak indicated LWC in the artificial cloud.
[4] The liquid water content is derived from the HISS flow calibration.
[5] Number 2 engine anti-ice OFF except Flt 15 and 18.
[6] Severe asymmetric shed required use of deice system (0.4 g). Flight aborted due to clogged HISS nozzles and apparent degradation of cloud (large water droplets).
[7] Severe asymmetric shed from forward head required use of deice system (0.47 g).
[8] Gentle asymmetric sheds; self correcting (0.13 g). Large blade void caused by impact with shed ice. Required repair to aft green blade (10-½ in. x 3-½ in.).
[9] LWC reading unreliable due to possible large water droplets

Figure 1



ICE COVERAGE FROM
JPL PHOTOGRAPHIC ANALYSIS
ICE COVERAGE (PERCENT)
ELAPSED TIME (MINUTES)
DATA FROM AFT ROTOR BLADE
0
4
8
12
16
0
10
20
30
40
50

found inboard of station 180 and only a thin ice buildup occurred outboard of station 275. Pieces of ice were taken from blade station 120 after flight 4 which were 3/4 inch in thickness (photo 4).

23. Natural icing flights were conducted at various airspeeds starting with a base line data flight at 90 knots true airspeed (KTAS) at a given LWC and temperature. During the flights, the aircraft was maneuvered with bank angles up to 30 degrees in both directions and airspeed changes to 40 knots indicated airspeed (KIAS) to evaluate any change in the handling qualities that might have occurred due to ice accretion. Cruise guide indications noted were normal for the conditions being tested. Qualitatively, no change in the handling qualities were noted. If a similar natural condition existed on subsequent tests, the target airspeed was varied to determine the apparent effects of ice accretion on the blades at an increased angle of attack. Four flights were conducted at the airspeed for maximum continuous power ($V_{m\,cp}$) of 136 KTAS, and that airspeed maintained for the duration of the flight except during handling qualities evaluation. Vibration levels remained constant at a given airspeed regardless of the time in the icing conditions; however a significant increase in the number of dents on the rotor blades were noted during the post flight inspection (para 25). One additional flight was conducted at 63 KTAS with no noticeable change in handling qualities.

24. An analysis of in-flight high speed photographs taken after exiting the artificial icing conditions indicated that the pieces of ice shed from the forward head advancing rotor blades were projected forward along the flight path of the aircraft. The ice would then impact the bottom of the succeeding advancing blade. Pieces of ice also passed through the retreating blades of the aft rotor system. The projected path indicated impact would occur on the underside of both the forward and aft rotor blades. A delamination and fiber separation of approximately 6 x 1/2 inch on the underside of the forward yellow rotor blade (photo 5, app E) was noted following flight 6. A blade delamination was also noted following flight 10 flown at -5° C in natural conditions. The delamination which occurred on the underside of the aft yellow blade was approximately 2-1/2 inches in diameter. The fiber separation and delaminations were repaired with EC2216 compound and allowed to cure overnight in a heated hangar (photo 6, app E).

25. Small dents and voids were detected during postflight inspection on the underside of the forward and aft rotor blades. Figures 2 and 3 show the location of all blade damage encountered during the icing tests. The majority of the dents were incurred during the natural icing flights conducted at $V_{m\,cp}$ airspeeds (flights 14, 17, 18, and 20). The largest blade void occurred during flight 9, behind the HISS, at a flow calibrated LWC of 1.2 gm/m^3 and -10° C (photo 7, app E). The voids marked with an arrow in figures 2 and 3 reflect blade damage that required repair (para 27). Annotations show the size of the damage and flight number. The YCH-47D, with unheated blades, can operate continuously at temperatures down to -5° C with up to 0.5 gm/m^3 LWC without incurring significant blade damage or asymmetric shedding. An ice detector is necessary to give the pilot an indication of the icing conditions, so he can keep the aircraft within established limits.

<u>Artificial Icing Environment</u>

26. Four flights were conducted behind the HISS to expand the LWC and temperature range with unheated blades (table 2). An average ESGW of

Figure 2. Ice Damage to the Bottom of the Fwd Rotor Blades

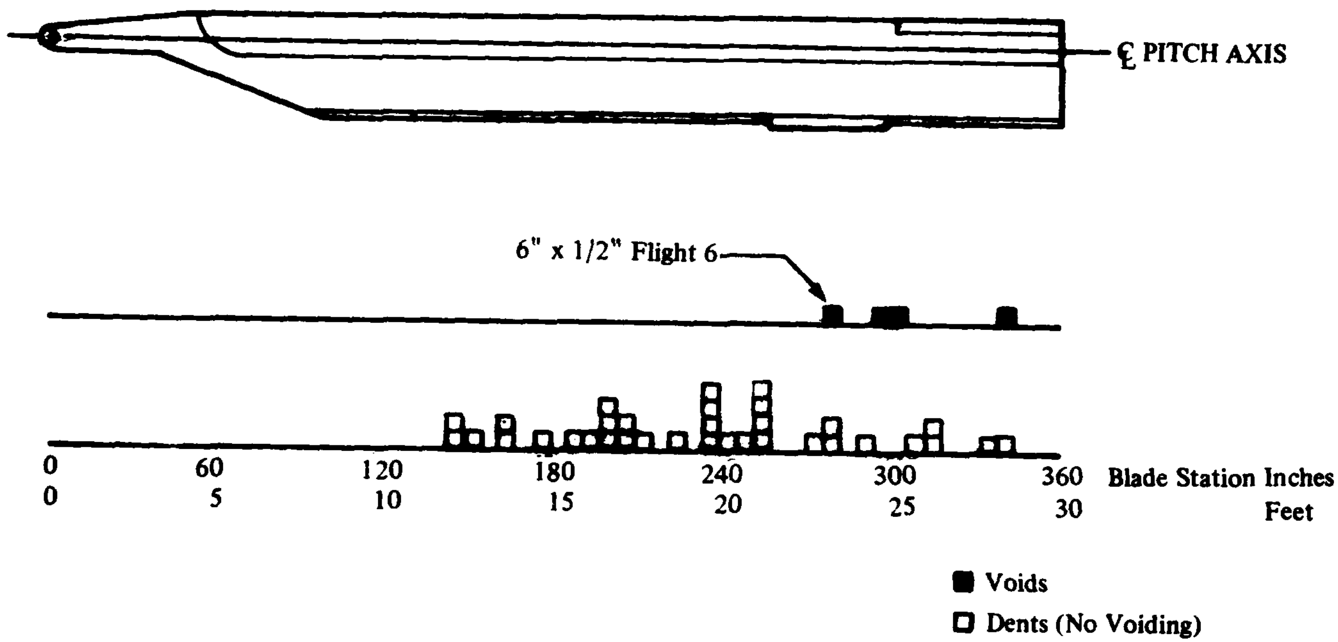
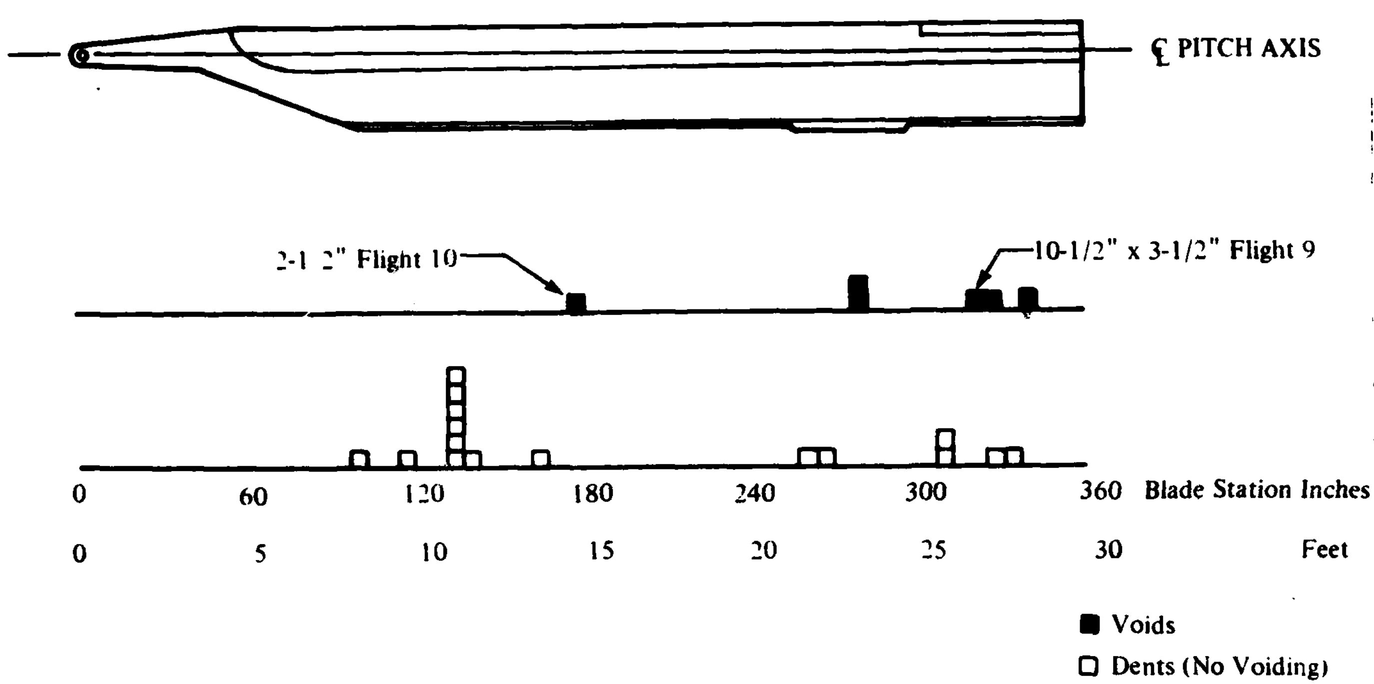


Figure 3. Ice Damage to the Bottom of the Aft Rotor Blades

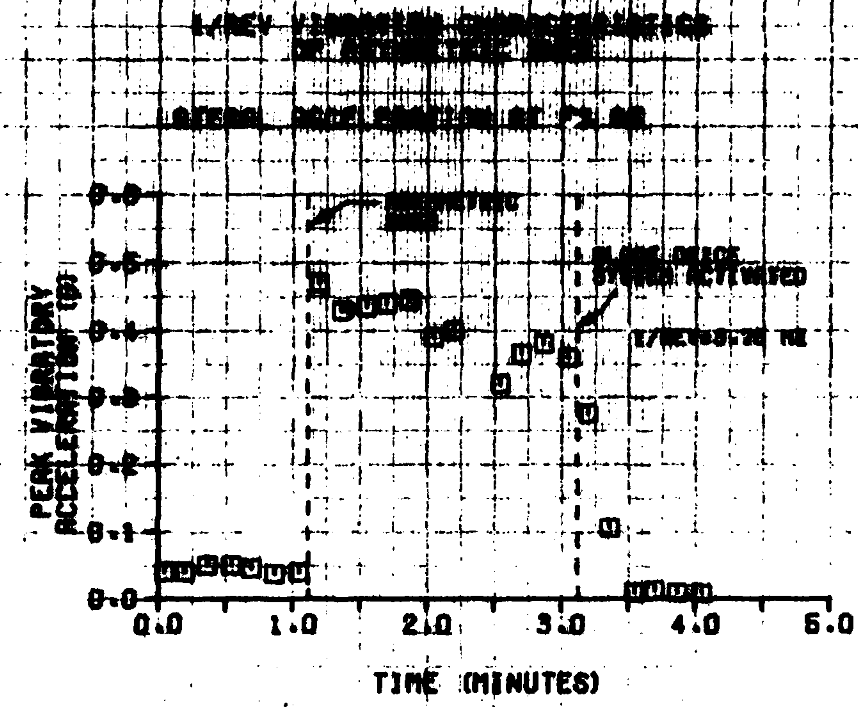


47,700 pounds and 90 KTAS was used for these tests. Two flights (5 and 8) were conducted at -19° C at 0.6 gm/m^3 LWC to investigate the icing effects at colder temperatures. Flight 5 was conducted with approximately 15 percent of the HISS nozzles frozen. Larger water droplets than normally noted at the same flow rate were observed on the windshield. The forward rotor system was immersed in the cloud, and 18 minutes into the test a 2-1/2 foot piece of ice shed from a forward rotor blade at station 180 (photo 8, app E). A lateral 1 per revolution acceleration of 0.4 g (VRS 9) resulted from the shed and the test aircraft exited the cloud. The blade track was measured 5 inches out of the tip path plane. Cruise quick indications were in the upper end of the normal operating range (green zone) prior to the shed then oscillated within the restricted flight band (yellow zone). An attempt to shed the ice on the 2 remaining blades was made by varying rotor speed from 216 to 235 rpm, changing the collective pitch setting and varying airspeed. Small longitudinal pulse inputs of 1/4 inch magnitude were also used. The vibration level could not be reduced using any of these methods and the deice system was manually activated. The vibration was eliminated within 30 seconds, which corresponded to the end of the second cycle (second heated mat in the blade). The test was repeated under similar conditions (flight 8) to verify the results with the larger droplets. Similar results were noted after 18 minutes of forward head immersion. An asymmetric shed occurred, producing a lateral 1 per revolution vibration of 0.47 g (VRS 9). The same techniques used on flight 5 failed to reduced the vibration level and the deice system was manually activated 21 minutes after initial immersion. Figure 4 shows the vibration amplitude change with the shed and the activation of the deice system. The 3, 6 and 12 per revolution vibrations showed negligible changes with the ice shed. The aft head was then tested in the same cloud and an asymmetric shed was encountered after 30 minutes of immersion and a mild lateral vibration ensued (photo 9, app E). The deice system was used to remove the remaining ice after pilot induced maneuvers failed to reduce the vibration. The unacceptable 1 per revolution lateral vibrations resulting from asymmetric rotor blade ice shedding at -19°C is a deficiency.

27. Flight 9 was conducted at -10° C and at a higher LWC than found in natural conditions at the St. Paul test site. The HISS water flow rate was set at 25 gal/min which produced a LWC of 1.2 gm/m^3 (fig 4, app B). The forward head was immersed for 30 minutes during which time mild intermittent asymmetric sheds and associated vibrations of 0.13g (VRS 3) occurred, but dissipated rapidly. High speed photography showed large pieces of ice shedding intermittently from the forward rotor system traveling past the aft pylon. One piece of ice, 2-1/2 inches in diameter, passed through the aft rotor system. The preponderance of the voids shown in figures 2 and 3 were detected during the postflight inspection (para 25). Further inspection revealed a large void (10-1/2 x 3-1/2 inches) and shredding of the outer fiberglass cover on the underside of the aft green blade (photo 10, app E) which grounded the aircraft. The risk of blade damage and asymmetric shedding with unheated rotor blades increases significantly at colder temperatures and higher LWC (para 25). The rotor blade damage incurred from ice sheds at -10°C and a flow calibrated LWC of 1.2 gm/m^3 (heavy icing) is a deficiency.

28. The rotor blade was repaired by a BV factory technician utilizing special equipment. The nomex honeycomb inner core and outer fiberglass cover was removed and a new core was installed and cured for 12 hours under heat and pressure. The core was then shaped to the contour of the blade and the bi-directional fiberglass outer cover installed. Heat and pressure for an additional

Figure 4


PEAK VIBRATORY
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.0
1.0
2.0
3.0
4.0
5.0
TIME (MINUTES)

12 hour period were required to cure the outer cover (photo 11, app E). The maintenance test flight showed no change in blade track or balance as a result of the blade repair.

29. The last unheated flight (12) behind the HISS was conducted at -5° C and the highest LWC (1.5 gm/m^3) of the test. The forward rotor system was immersed in the HISS cloud for 33 minutes. Although there was continual shedding similar to that in flight 9, there were only slight lateral vibrations which were easily corrected by varying rpm or collective position. Ice shedding from the rotor system impacted on the windshield and fuselage. The ice striking the windshield was very soft, breaking into patches of slush. Postflight inspection revealed no apparent blade damage.

Snow Environment

30. Two unheated blade flights at the heavy gross weight were conducted in a heavy snow environment. Flight 7 was conducted at a temperature of -11° C and an average pressure altitude (PA) of 6000 feet. Flight 11 was conducted at -6° C and 2600 feet PA and was 20 minutes in duration. During the first minute in the cloud trace ice was detected; however, the conditions changed to heavy snow for the remainder of the flight. The visibility in the snow storm during both flights was less than 1/4 mile. During both flights the number 2 engine anti-ice was left OFF. No variation in engine or aircraft performance was noted during these tests in snow.

ENGINE AND AIRCRAFT PERFORMANCE

31. The effects of ice on engine and aircraft performance was also evaluated during these tests. These evaluations included icing of the engine inlet screens, the engine "D" ring, and power required penalties caused by rotor blade ice.

Inlet Screens

32. Engine air inlet bypass screens were installed on the YCH-47D. The capability of the screens to protect the engines from ice ingestion was investigated during all icing tests. The upper and lower bypass panels located on the back of the screens were removed to allow for reverse airflow to the engines should the screen become blocked with ice. Ice texture and thickness on the engine inlet screens varied with LWC and temperature. Flights in natural conditions, at a low LWC (light icing), produced a honeycomb ice structure on the outside of the screen (photo 12, app E). At higher LWC's, behind the HISS, the screen was completely covered with ice and then self-shed periodically (photo 13, app E). The solid composition of the ice restricted air flow passing through the front of the screen. Thin ice buildups were observed on the underside of the inlet screen; however, they caused no damage when injested by the engine. The YCH-47D operated continuously in light icing conditions and in moderate icing conditions with engine inlet bypass screen installed and the upper and lower bypass panels removed, without damage to the engine. The following caution should be added to the YCH-47D operator's manual if an operational icing envelope is established:

CAUTION

> The upper and lower bypass panels on the engine inlet screen must be removed before operating in forecasted or known icing conditions.

Bleed Air Anti-ice

33. Testing was conducted with one engine bleed air anti-ice system OFF to examine ice buildup on the engine "D" ring and transmission shroud. Theory and previous testing indicated that the engine screens ice over causing reverse air flow through the bypass panels and thereby separating water droplets from the air. All flights except 15 and 18 were conducted with the number 2 engine anti-ice OFF. On those two flights the number 1 engine anti-ice was OFF and the number 2 engine anti-ice was ON. Imagery from the two fiber optics,which were connected to a TV camera and monitored in the cabin, displayed the inside surface of the engine inlet screen and the engine "D" ring. No indication of ice accretion on the "D" ring during flight was perceptible on the video monitor. After shutdown the engine screens were removed to inspect for ice. On only one flight was there any positive evidence of ice buildup remaining on the "D" ring. Immediate postflight inspection of flight 5, flown at -19° C, showed melting ice from the 11 o'clock to 3 o'clock position on the "D" ring (photo 14, app E). Frozen HISS nozzles during this flight created large water droplets (para 26). Considerable heat radiates from the engine inlet and around the transmission shroud which melted any ice forming on the surfaces. Small water droplets were visible on these surfaces during most postflight inspections. There was no evidence of foreign object damage on either engine resulting from these icing tests. BV estimated bleed air losses to operate with the engine anti-ice ON was 260 horsepower (ref 6, app A). Currently the operator's manual states that flights in icing condition are conducted with the engine anti-ice ON at temperatures below 4°C. Test results indicate flights in continuous light icing conditions and snow down to -15°C, with the engine anti-ice OFF, were accomplished without incurring engine damage. The engine anti-ice envelope could therefore be expanded to include operations in continuous light icing and snow down to -15°C with the anti-ice OFF. The following note should be added to the operator's namual if an operational icing envelope is established:

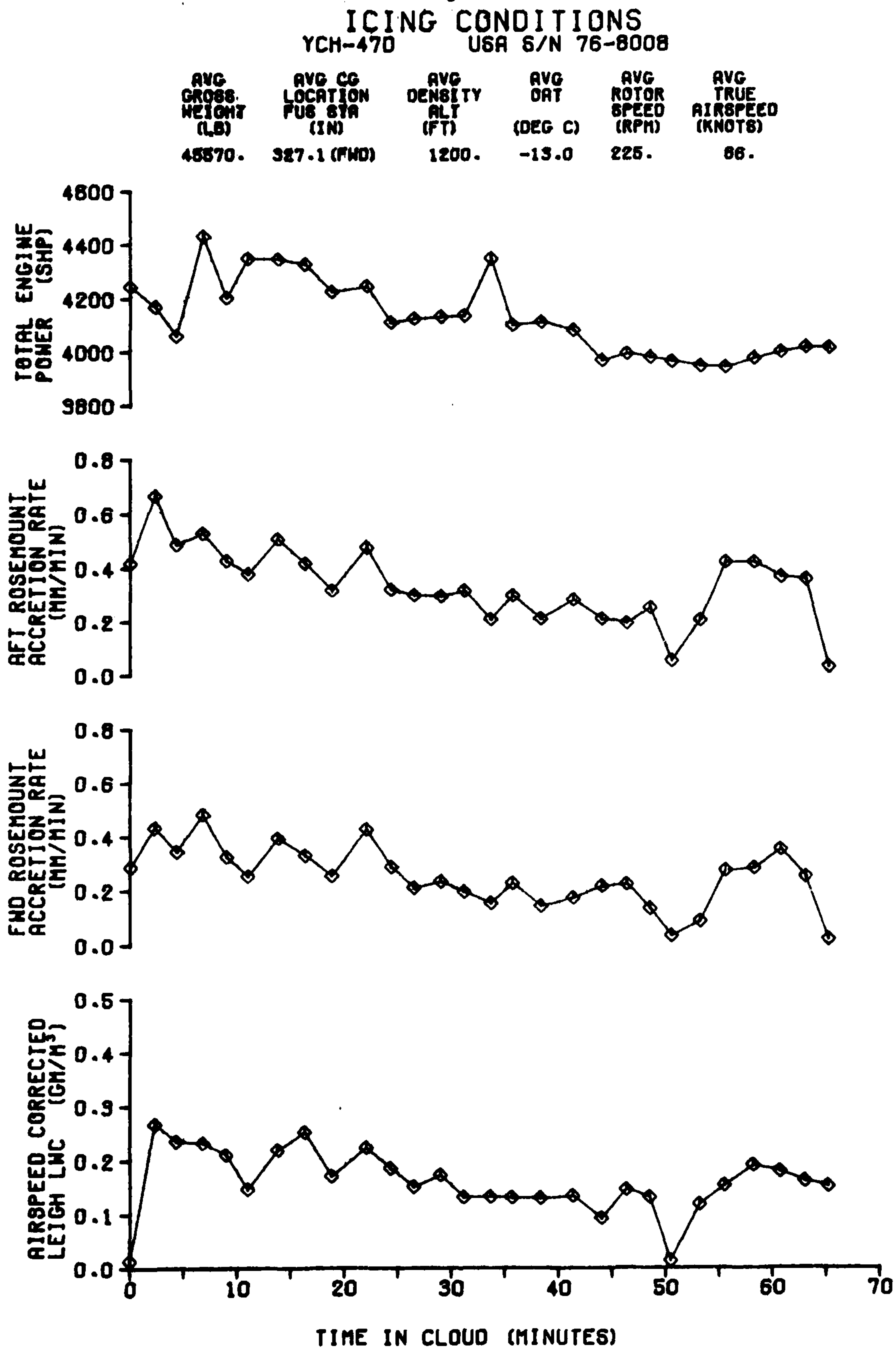
NOTE

> Flights in icing conditions, with the engine anti-ice ON, will reduce range and endurance due to increased fuel consumption.

Power Required

34. Any increase in power required caused by ice accretion was masked by fuel burn off. A typical time history of flight shows the total engine power required during a 66 minute flight in light icing conditions of 0.2 gm/m^3 LWC (figure 5). Power required gradually decreased throughout the flight despite ice buildup. A cloud sweep was conducted upon entering icing condition to determine the altitude which produced the highest LWC. The flight was then continued at that altitude and at a constant airspeed until conditions changed to provide maximum exposure to the icing condition. This flight technique makes a direct comparison of performance

Figure 5


ICING CONDITIONS
YCH-47D USA S/N 76-8008
AVG GROSS WEIGHT (LB) 45570.
AVG CG LOCATION FUS STA (IN) 327.1 (FWD)
AVG DENSITY ALT (FT) 1200.
AVG OAT (DEG C) -13.0
AVG ROTOR SPEED (RPM) 225.
AVG TRUE AIRSPEED (KNOTS) 86.
TOTAL ENGINE POWER (SHP)
3800
4000
4200
4400
4600
AFT ROSEMOUNT ACCRETION RATE (MM/MIN)
FWD ROSEMOUNT ACCRETION RATE (MM/MIN)
0.0
0.2
0.4
0.6
0.8
AIRSPEED CORRECTED LEIGH LWC (GM/M³)
0.0
0.1
0.2
0.3
0.4
0.5
0
10
20
30
40
50
60
70
TIME IN CLOUD (MINUTES)

data in icing condition versus clear air data difficult. BV performed an extensive analysis of the performance degradation caused by icing, and their conclusions in reference 6, appendix A, show the following performance penalities comparing clear air versus icing data at a $W/\sigma\ [(225/N_R)^2] = 52625$ pounds:

a. Approximately 12.5 percent decrease in best range.

b. Eleven percent increase in torque per engine at 135 KTAS.

To substantiate these values to a higher level of confidence, further testing in natural icing conditions is required.

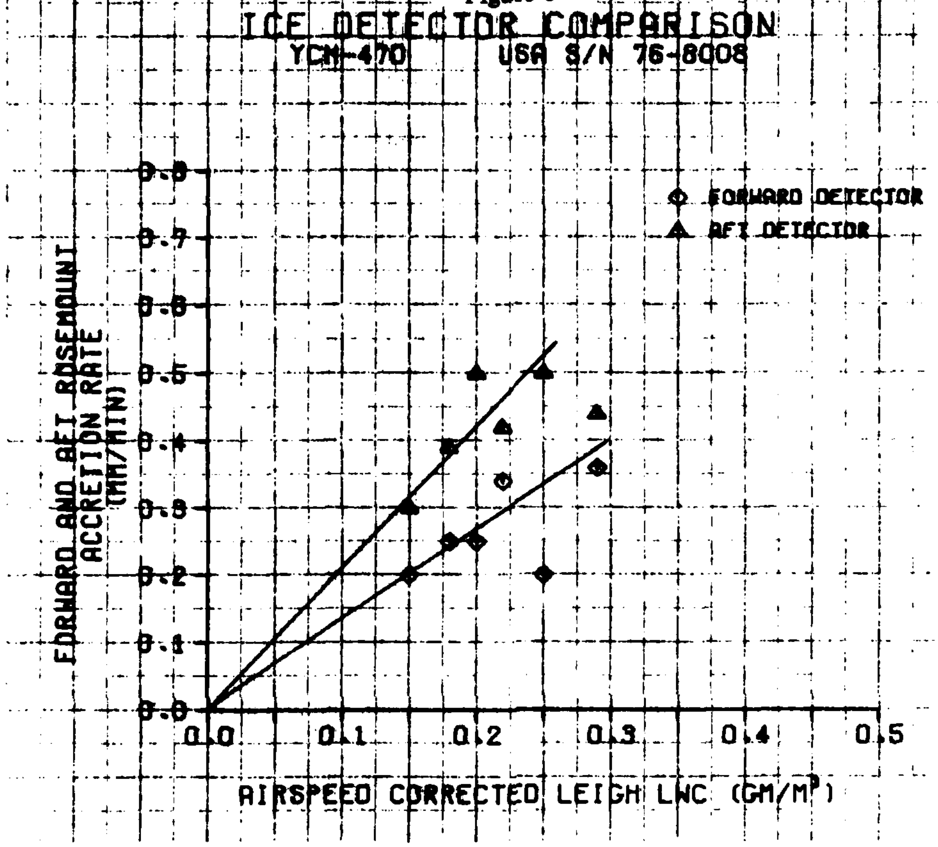
ICING ENVIRONMENT QUANTIFICATION

35. The YCH-47D was equipped with five ice detectors: the Leigh Mark XII aspirated ice detector; two nonaspirated Rosemount 871FA ice detectors; a vernier ice accretion meter developed by the British (the Harvey Smith device) and an airfoil accumulation device. The outputs of the three electrical detectors (Leigh and Rosemount) were recorded by the onboard data system (app C), while the performance of the Harvey Smith device and the airfoil were recorded by the flight crew. Time histories of the outputs from the three electrical devices (fig 4) showed similar trends although no calibration for LWC versus ice accretion rate existed for the two installed Rosemount detectors. An average accretion rate for each natural icing flight for the forward and aft detector is shown in figure 6. The aft Rosemount detector appeared to accrete ice faster than the forward Rosemount detector. This variation was attributed to the higher airflow on the aft probe due to its location on the pylon. Since either of these probes could be selected to operate the blade deice system, the aft probe would cause the system to operate approximately twice as often as the forward. The disparity in ice detection indications due to location indicated further testing will be required to determine a satisfactory position for the ice detector for a production system.

36. The Leigh Mark XII was evaluated during all natural and artificial flights. The limited depth of the HISS plume precluded immersing the detector for the total flight. The detector was immersed for a maximum of 4 minutes in the lower portion of the HISS cloud and the peak indicated value recorded (tables 2 and 3). At LWC's below 0.7 gm/m^3, the values were comparable to the HISS calibrated LWC. However, when the HISS flow rate was increased above 13 gal/minute (LWC 0.65 gm/m^3) the correlation did not exist (table 3). The manufacturer's information manual shows the indicator is unable to accurately measure large water droplets (above 40 microns) such as observed on flights 9 and 12. The detector appeared to operate satisfactorily once established in natural icing conditions. There were two occurrences (flights 2 and 17) of intermittent operation of the Leigh Mark XII detector noted by a fault light on the control panel within five minutes after entering icing conditions. The fault was corrected by recycling the system circuit breaker. The intermittent operation of the Leigh Mark XII detector within five minutes after entering the icing conditions was a shortcoming.

37. The Harvey Smith device was provided by BV and is a "V" shaped device that allowed ice accretion to be read directly from an embossed scale (photo 15, app E).

Figure 6


ICE DETECTOR COMPARISON
YCM-470 USA S/N 76-8008
FORWARD DETECTOR
AFT DETECTOR
FORWARD AND AFT ROSEMOUNT ACCRETION RATE (MM/MIN)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.0
0.1
0.2
0.3
0.4
0.5
AIRSPEED CORRECTED LEIGH LWC (GM/M³)

The ice accretion was read approximately every two minutes by the copilot. The device was deiced by hand prior to starting a new record. The ice accretion rate was recorded and, using a chart for a given airspeed, then converted to a LWC (fig. 2, app D). The ice accretion indicated on this test device exhibited the same trends as those given by the Rosemount and Leigh devices. This test instrument required excessive crew time be devoted to operating and calculating the ice environment and thus is unsuitable for operational use. Night use of this device would also be restricted by inadequate lighting. The Harvey Smith ice dector provides an approximate accretion rate which may be converted to a LWC, however the high crew workload necessary to use the device makes it operationally impractical.

38. Ice accretion on the cockpit free-air-temperature (FAT) probe was compared with ice accretion on the Harvey Smith and Rosemount ice detectors. Similar trends were obtained from qualitative correlation attempted in natural icing conditions and low LWC's as shown in table 3. The ice buildup appeared to correlate closely with the Harvey Smith in rate indications and elapsed time; however, an accurate means of measuring the ice thickness was not available to the pilot (photo 16, app E). To determine the icing environment in terms of LWC an accurate measurement of ice accretion over a short period of time must be recorded and then corrected for airspeed. Similar problems were incurred using the windshield wipers and the airfoil detector to evaluate the environment. The use of the FAT probe, windshield wipers, or other existing protuberances to quantify icing conditions is restricted to daylight conditions and, since it requires considerable crew time to calculate the icing environment, is unsuitable for operational use.

VIBRATION

39. The aircraft vibration, exclusive of ice sheds noted previously, were evaluated qualitatively during the cold weather operations. Vibration levels became excessive as airspeeds approached 145 (KIAS) at 225 rpm. Above this airspeed, vibration increased rapidly with unacceptable levels reached prior to V_H (the maximum level flight airspeed). Vibration levels were predominantly at 6 per revolution and would effectively restrict the helicopter to 145 KIAS for continuous operation. Blade noise was more pronounced at temperatures below -5° C; however, a reduction in vibration levels and a substantial decrease in blade noise was achieved by reducing rotor speed to 221 rpm. The high vibration level at airspeeds above 145 KIAS remains a shortcoming, as previously reported (ref 7, App A).

COMPONENT OPERATION

Droop Stop Covers

40. The failure of the aft droop stop to engage due to ice accumulation was a deficiency noted during the previous icing tests. A droop stop cover was installed on the aft rotor head to protect the stops, balance arms, and springs as shown in Photograph 17. Ice did not accumulate on the droop stop mechanism after installation of the covers; however, the cover precludes visual observation of the droop stop position during shut down. The droop stop position can be determined by observing the aft rotor tip path plane at low rotor speeds. The aft droop stop covers provided adequate ice protection in the conditions tested.

Fuel Vent and Cabin Heater Drain Modification

41. Prior testing revealed partial or total blockage of all fuel vents and the cabin heater fuel drain (due to ice accumulation). A shroud was installed on all the external fuel vents of the YCH-47D to eliminate the problem. Flights in icing conditions produced ice on the shroud (photo 18, app E) but the vent tubes remained clear. On the production CH-47D aircraft, the vent outlets will exit internal to the filet fairing and a flush-mounted screen will be incorporated in the filet fairing over the vent line outlet. This vent modification is part of Engineering change proposal (ECP714) and is in the process of being incorporated on CH-47C aircraft. On aircraft not modified with ECP 714, a similar type of fuel vent shroud should be installed on the CH-47 A, B and C model aircraft prior to flight in icing conditions.

42. The cabin heater drain was modified by extending and deflecting the drain tube (photo 19, app E). No blockage was noted on any of the icing test flights. With the drain modification installed, the caution recommended in last years report should be deleted (ref 1, app A). The operation of the cabin heater drain modification was satisfactory.

Oil Coolers in the Aft Pylon

43. The number 1 and 2 engine transmissions and combining transmission oil coolers are mounted on top of the combining transmission in the aft pylon. Ice accreted on the forward portion of the cooling fins covering 120 degrees of the circular cooling surface (photo 20, app E). The oil cooler temperatures recorded during the icing tests were below 80° C (the design bypass temperature) and therefor ice accretion on the oil coolers' fins did not affect the cooling system. The operation of the oil coolers in icing conditions was satisfactory.

Transmission Oil Pressure Sensor

44. During the test flights, ice accreted on the electrical connector of the combining transmission oil pressure transducer. The engine and combining transmission oil pressure sensors are located in the forward portion of the aft pylon behind the transmission oil coolers. The two engine sensors are positioned with the electrical connectors on the bottom of the sensor. The combining transmission sensor is mounted with the connector on the top allowing ice that has accreted on the connector and top of the sensor to melt and collect inside the electrical plug. This was detected as a fluctuating oil pressure with some indications of no oil pressure. To provide redundancy a separate oil pressure sensor is installed in the pressure line and connected to the master caution panel. The erratic operation of the combining transmission oil pressure gage, caused by ice accretion on the pressure transmitter electrical connection, is a shortcoming.

Cockpit Leaks

45. Cockpit leaks were detected on five different occasions. Ice that remained on the airframe and rotor heads melted and leaked through the overhead console. During engine starts, as much as two quarts would drain through the forward lowest points of the upper console onto the lower console. The electrical switches, lights, and engine condition levers are susceptible to short circuits when operating in this environment. The Water leaking from forward pylon area through the overhead console is a shortcoming.

NON ICE RELATED PROBLEM AREAS

Power Management

46. The power management characteristics were qualitatively evaluated throughout the icing tests. At low power settings, the torque split was unacceptable and reached torque of 20 percent. The torque split, predominantly below 50 percent, required constant adjustment and monitoring when making power changes during low power maneuvers. Engine trimming was also required to compensate for rotor droop of ±4 rpm from low to high power settings. If rotor droop is not pilot compensated, an increase in aircraft vibration results until the self-turning vibration absorbers adjust to the lower rotor rpm. The unsatisfactory power management characteristics of the T55-L-712 engines at low power settings is a shortcoming as previously documented (ref 7, app A).

Fiberglass Rotor Blade Trim Tab

47. The fiberglass rotor blade trim tabs are initially set at the factory and are not field adjustable. The trim tabs on the blades used on this test would not retain the factory preset trim and would change as much as 2 degrees during a 1.5 hour flight. The out-of- track blade condition increases the already high vibration level at higher airspeeds. The inability of the blade trim tab to retain the preset deflection is a shortcoming.

Hydraulic Power Control Module Support Structure

48. The number one hydraulic power control module support structure located in the forward pylon developed numerous cracks. Total time on the airframe was approximately 190 hours. Three angle supports with cracks working outward from the rivet holes were replaced. Other working rivets on the support structure also required replacement. The structural inadequacy of the number 1 hydraulic power control module support is a shortcoming.

Localizer Needle Oscillation

49. The AN/ARN 123 VHF Navigation and Instrument Landing System Receiver is currently installed in the YCH-47D. When tuned to an instrument landing system (ILS) frequency the course deviation indicator showed peak oscillations of ±1/2 degree (20 percent) in amplitude with an approximate frequency of 1 cycle per second. The oscillations were evident at 225 and 230 rotor rpm; however, they could be eliminated at 220 and 235 rpm. Localizer information, at the normal rotor rpm of 225, was unsatisfactory to execute an approach in marginal weather conditions. The localizer needle oscillating ±1/2 while on a precision instrument approach at 225 rotor rpm is a shortcoming.

Interphone System

50. The interphone system was evaluated during cold weather testing. The noise level in the cockpit and especially in the aft cabin area requires the use of earplugs in conjunction with the SPH-4 helmet to avoid permanent hearing damage. The new interphone set (C6533/ARC) installed in the YCH-47D has a reduced maximum volume level compared to the C1611/AIC currently installed in the A, B and C

model Chinooks. With just the helmet, the interphone system (C6533/ARC) has insufficient volume to allow monitoring the intercommunications of the crew. Add machine gun firing and external load operations in a tactical situation to the normal noise of the helicopter and communications within the aircraft would be inadequate. These communications restrictions could impair the safety of the crew and aircraft. The insufficient volume of the interphone set (C6533/ARC) is a shortcoming, as previously reported (ref 7, app A).

CONCLUSIONS

GENERAL

51. The following conclusions were reached upon completion of the YCH-47D icing tests:

a. The CH-47D, with unheated rotor blades, can operate continuously at temperatures dowr to -5° C with up to 0.5 gm/m^3 LWC, without incurring significant blade damage or asymmetric shedding (para 25).

b. The risk of blade damage and asymmetric shedding with unheated blades increases significantly at colder temperatures and higher LWC (para 27).

c. A reliable cockpit indication of the icing environment is necessary (para 25).

d. The aft droop stop covers, fuel vent screens and modified cabin heater drain performed satisfactorily under all conditions tested and corrected the previously reported deficiencies (para 40, 41 & 42).

e. The Harvey Smith ice detector provides an approximate accretion rate which maybe converted to a LWC, however the high crew workload necessary to use the device makes it operationally impracticable (para 37).

f. Flights in continuous light icing conditions and snow down to -15° C, with engine anti-ice OFF were accomplished without incurring engine damage (para 33).

g. The use of the FAT probe, windshield wipers, or other existing protuberances to quantify icing conditions is restricted to daylight conditions and, since it requires considerable crew time to calculate the icing environment, is unsuitable for operational use (para 38).

DEFICIENCIES

52. The following deficiencies for flight in icing conditions were identified and are listed in order of decreasing importance:

a. Unacceptable 1 per revolution lateral vibrations resulting from asymmetric rotor blade ice shedding at -19° C (para 26)

b. The rotor blade damage incurred from ice shed at -10° C and a flow calibrated LWC of 1.2 gm/m^3 (heavy icing) (para 27).

SHORTCOMINGS

53. The following ice related shortcomings were identified and are listed in order of decreasing importance:

a. The erratic operation of the combining transmission oil pressure gage caused by ice accretion on the oil pressure transmitter electrical connector (para 44)

b. The water leaking into the cockpit through the overhead console (pare 45)

c. Intermittent operation of the Leigh Mark XII ice detector within five minutes after entering the icing conditions (pare 36)

54. The following additional shortcomings were identified:

a. The unsatisfactory power management characteristics of the T 55-L-712 engines at low power settings, documented previously (para 46)

b. The high vibration level at airspeeds above 145 KIAS, also previously reported (para 39)

c. The inability of the blade trim tab to retain the preset deflection (para 47)

d. The structural inadequacy of the number 1 hydraulic power control module support (para 48)

e. The localizer needle on the course deviation indicator oscillating ±1/2 degree (20 percent) while on a precision instrument approach at 225 rotor rpm (para 49)

f. The insufficient volume of the interphone set (C6533/ARC), as previously reported (para 50).

RECOMMENDATIONS

55. Establish a limited operational envelope for flights in icing conditions (para 14).

56. Expand the engine anti-ice envelope to include operations in continous light icing and snow down to -15°C with the anti-ice OFF (para 33).

57. Correct the shortcomings as soon as practical.

58. Installation of the aft droop stop cover and modified cabin heater drain should be required prior to flights in icing conditions (paras 40 and 42).

59. Installation of a fuel vent shroud on CH-47A, B, and C model aircraft prior to flights in icing conditions (para 41).

60. Delete the caution recommended in USAAEFA Project No. 78-18 (para 42).

61. Install an ice detector that gives the pilot an indication of icing conditions to remain within established limits (para 25).

62. Further testing is required to establish the optimum deice cycle time and time between cycles for best shedding with minimum power requirement or ice run back for a production blade deice system (para 18).

63. Conduct further testing to determine a satisfactory position for the ice detector for a production system (para 35).

64. The following caution should be placed in the operator's manual if an operational icing envelope is established (para 32):

CAUTION

The upper and lower bypass panels on the engine inlet screen must be removed before operating in forecasted or known icing conditions.

65. The following note should be placed in the operator's manual if an operational icing envelope is established (para 33):

NOTE

Flights in icing conditions, with the engine anti-ice ON, will reduce range and endurance due to increased fuel consumption.

APPENDIX A. REFERENCES

1. Final Report, USAAEFA Project No. 78-18, *Artificial Icing Test, CH-47C Helicopter with Fiberglass Rotor Blades,* July 1979.

2. Final Report, USAAEFA Project No. 78-21, *Microphysical Properties of Artificial and Natural Clouds and Their Effects on UH-1H Helicopter Icing,* August 1979.

3. Test Plan, USAAEFA Project No. 79-07, *YCH-47D Icing Evaluation,* October 1979.

4. Technical Manual, DEPTM 55-1520-240-10, *Operator's Manual, Army Model YCH-47D Helicopter,* 21 March 1980.

5. Letter, AVRADCOM, DRDAV-DI, 26 January 1980, subject: Airworthiness Release for Conduct of the YCH-47D Icing Evaluation, USAAVRADCOM/USAAEFA Project No. 79-07.

6. Report, Boeing Vertol Company, D414-10048-1, *Boeing Vertol Analysis and Discussion, YCH-47D Icing Testing,* 1980.

7. Final Report, USAAEFA Project No. 79-06, *Preliminary Airwothiness Evaluation of the YCH-47D Helicopter,* May 1980.

8. Handbook, All American Engineering Co., SM-280B. *Installation, Operation, and Maintenance Instructions with List of Parts, Helicopter Icing Spray System (HISS),* with Change 1, November 1974.

9. Report, Meteorology Research, Inc., No. MRI 80 dFR-1748, *Droplet Size and Liquid Water Characteristics of the USAAEFA (CH-47) Helicopter Spray System and Natural Clouds as Sampled by a JUH-1H Helicopter*, April 1980.

APPENDIX B. DESCRIPTION

HELICOPTER ICING SPRAY SYSTEM (HISS)

1. The Helicopter Icing Spray System (HISS) is installed in a modified CH-47C helicopter and consists of an internally mounted 1800-gallon water tank and an external spray boom assembly suspended 19 feet beneath the aircraft from a cross-tube through the cargo compartment. Hydraulic actuators rotate the cross-tube to raise and lower the boom assembly. Both the external boom assembly and water supply can be jettisoned in an emergency. The spray boom consists of two 27-foot center sections, vertically separated by 5 feet, and two 17.6-foot outriggers. The outriggers are swept back 20 degrees and angled downward 10 degrees giving a tip to tip boom width of 60 feet. A total of 97 Sonic Development Corporation Sonicore Model 125-HB nozzles are installed on the two center sections. The spray cloud is generated by pumping water at known flow rates from the tank to the nozzles on the boom assembly, using aircraft engine compressor bleed air to atomize the water. A schematic is shown in figure 1, and a detailed description is given in references 2, 8, and 9, appendix A.

2. A calibrated outside air temperature probe and a dew point hygrometer provide accurate temperature and humidity measurement. An aft-facing radar altimeter is mounted at the rear of the HISS to allow positioning the test aircraft at a known standoff distance. Because of gross weight and center of gravity limitations, the aft fuel cells of the helicopter are left empty and only 1500 gallons of water are carried. For icing tests, a chemical with coloration properties similar to sea marker dye is added to the water and imparts a yellow color to the ice.

3. At the 150 to 250 foot standoff distances used for icing tests, size of the visible spray cloud is 8 feet deep and 36 feet wide. The measured drop size distribution and liquid water content (LWC) variation of the spray cloud are shown in figures 2 and 3. For a 90 KTAS test condition, the average LWC of the spray cloud was controlled by adjusting the water flow rate as shown in figure 4. This relation was theoretically derived assuming mass conservation (no evaporation) and a uniform water distribution over the cloud cross-sectional area (288 ft^2). However, this line also provides a close fit to averaged LWC data measured in flight at relative humidity conditions above 65 percent and temperatures below -5°C.

TEST AIRCRAFT DESCRIPTION

General

4. The YCH-47D is a twin-turbine engine, tandem rotor helicopter designed for internal and external cargo transport during visual and instrument, day and night operations. It is powered by two T55-L-712 shaft-turbine engines housed in pylons mounted on the aft fuselage. The engines drive tandem, three-bladed, fully-articulated, counterrotating rotors. The drive train system consists of two engine transmissions, a combining transmission, and a forward and aft transmission. The combining transmission receives power from the engine transmissions and drives the forward transmission through drive shafting housed in a tunnel along the top of the fuselage. The aft transmission is driven by a drive shaft running from the aft section of the combining transmission. A gas turbine auxiliary power unit mounted in the aft pylon, drives a hydraulic pump and 20 kilovolt amps (KVA) generator to provide power to the aircraft systems when the rotors are stationary. Fuel is carried in six tanks mounted in pods on each side of the fuselage. The helicopter is equipped with four nonretractable landing gear with steering provided by the right aft gear.

Figure 1.
HISS Schematic

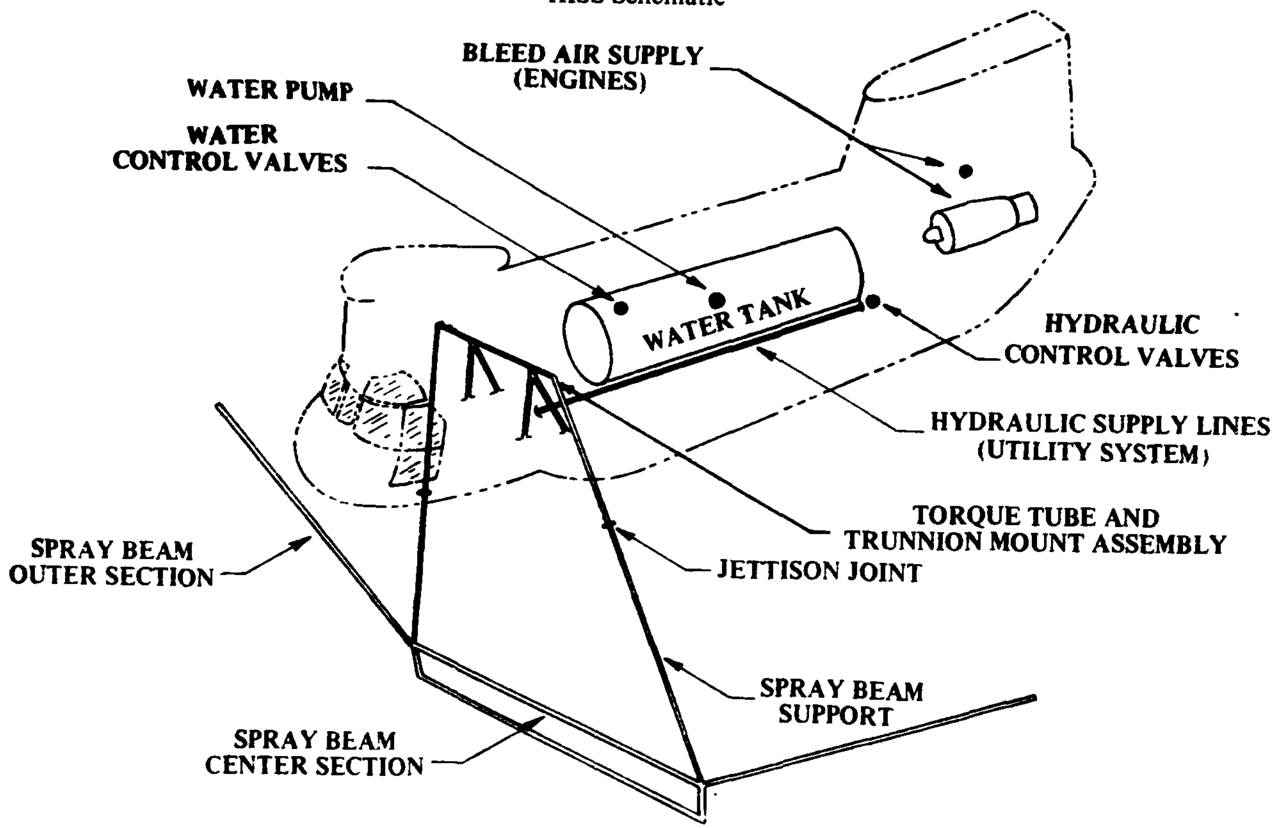


Figure 2.
Vertical Variation of Cloud Droplet

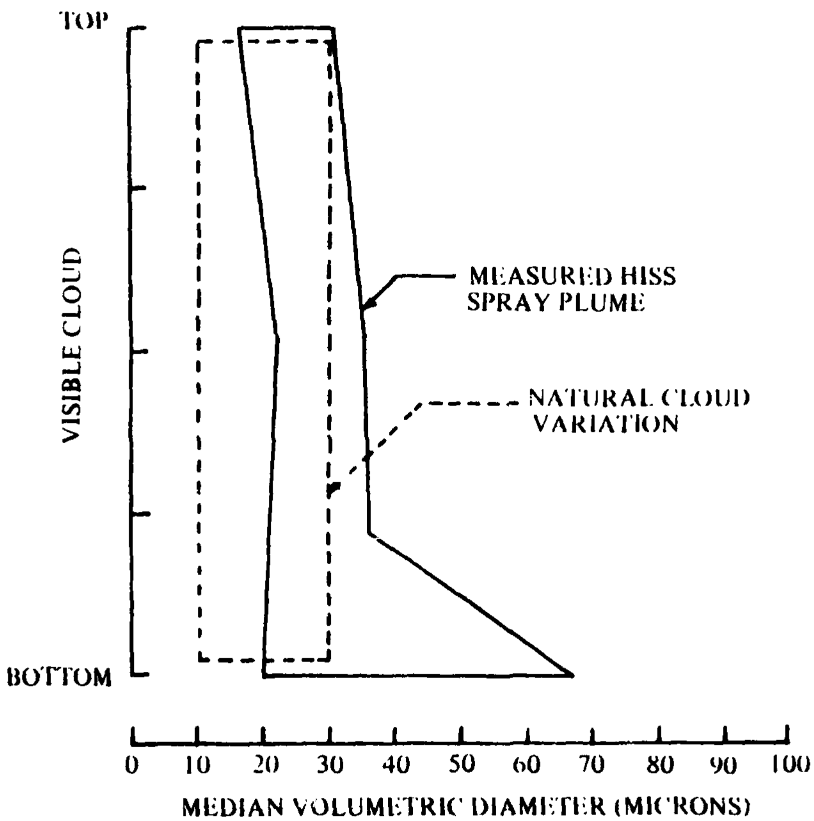


Figure 3.
Vertical Variation of the Visible Cloud

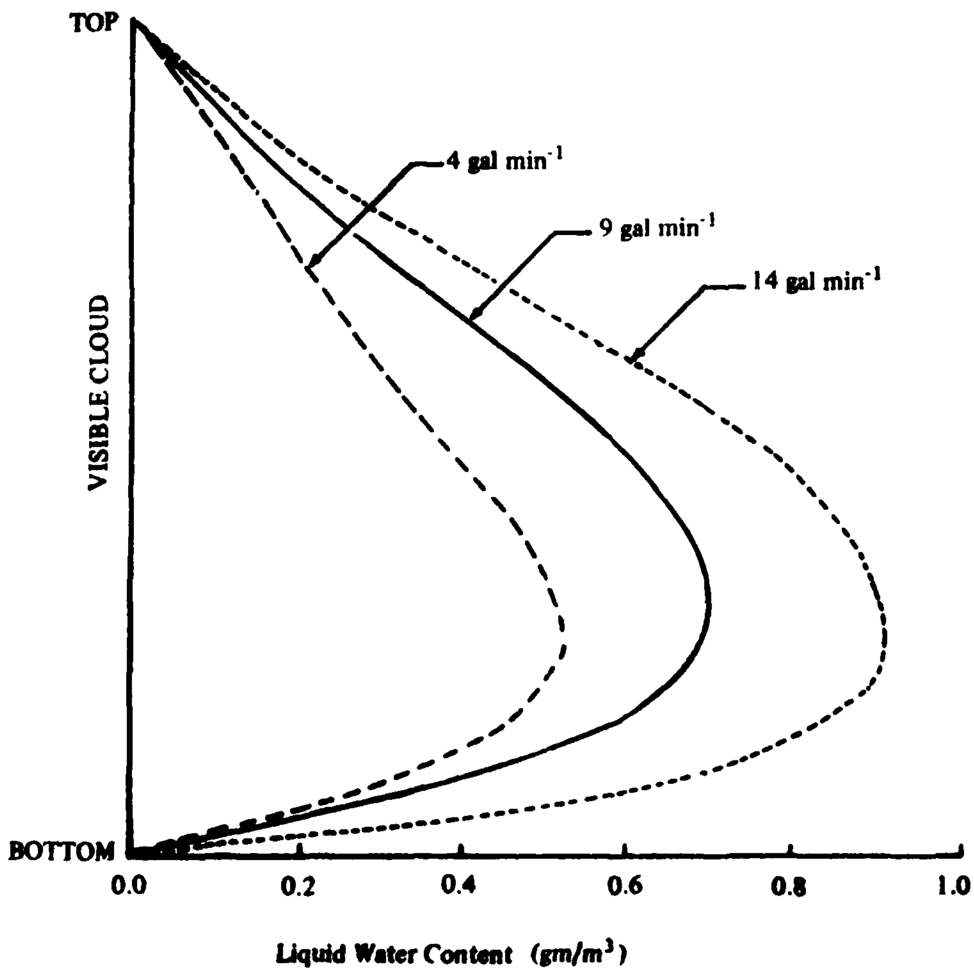
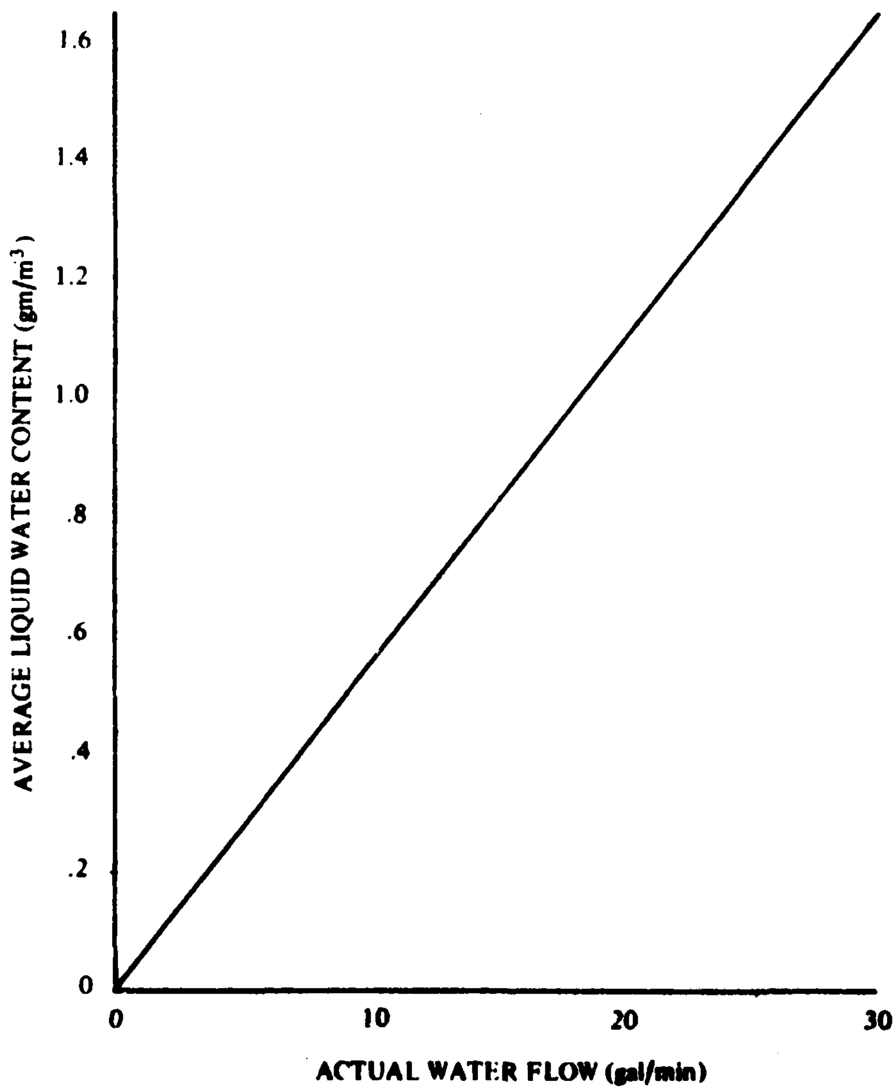


Figure 4. HISS Water Flow versus Liquid Water Content



Entrance to the helicopter is provided through a door located on the forward right side of the cargo compartment or through a hydraulically-operated cargo ramp located at the rear of the cargo compartment. The helicopter is equipped with standard tandem rotor cockpit controls and an advanced flight control system (AFCS). The allowable center-of-gravity (cg) envelope is shown in figure 5 and ballast configuration, using movable water storage tank and lead weights, are shown in photos 1 & 2. A further description of the aircraft is found in reference 4, appendix A.

Fiberglass Rotor Blade Deice System

5. The test YCH-47D, S/N 76-8008 was equipped by Boeing Vertol with fiberglass rotor blades with integral deice blankets. The electrical power and control system for deicing the blades was a prototype configuration not representative of a production system. The system consisted of the following elements:

a. Fiberglass rotor blades with integral electrical deicing blankets

b. Auxiliary 40 KVA generator mounted on the aft transmission

c. Cabin installed, palette mounted system control and power distribution elements

d. Hub mounted electrical power distribution elements

e. Forward and aft pylon mounted ice detectors

f. Fuselage mounted heated FAT sensor

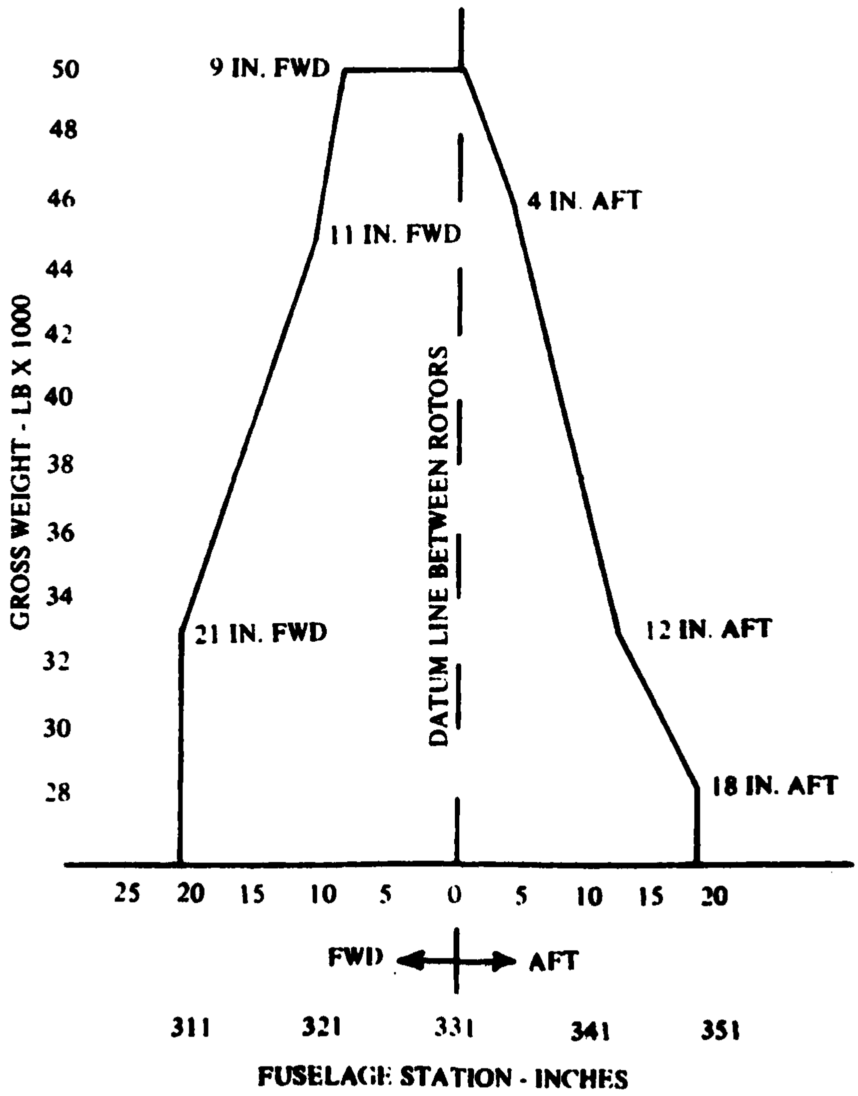
g. Cockpit display and controls.

Fiberglass Rotor Blades

6. The rotor blades are 30-foot radius with a 32-inch chord and operate at 225 rpm. The planform is constant-chord between station 97 and the tip; from station 97 inboard it transitions to a circular root end section. The blades have a 12 percent thick VR-7 airfoil out to 85 percent radius, tapering uniformly to an 8 percent thick VR-8 airfoil at the tip. The twist is -12 degrees. The blade is designed to operate at 225 rpm.

7. The blades are of fiberglass construction with a nomex honeycomb core. The "D"- shaped spar is constructed of fiberglass reinforced composite, terminating at the root end in a "wrap-around" single pin joint. The nose of the spar includes balance weights and provisions for a deice heat blanket. Outboard, the spar contains provisions for forward and aft weight fittings. The airfoil fairing aft of the spar is formed from a banded subassembly of nonmetallic honeycomb core covered with cross-plied (±45°) fiberglass skins. The fiberglass trailing edge member has a built in "cusp" angle. A titanium leading edge cap is incorporated to provide leading edge damage tolerance, erosion protection and lightning protection. A replaceable electro-formed nickel protective cap is installed from the 85 percent radius to the tip. A diagram of the blade is presented in figure 6.

Figure 5.
YCH-47D USA 76-8008
Gross Weight - Center of Gravity Diagram



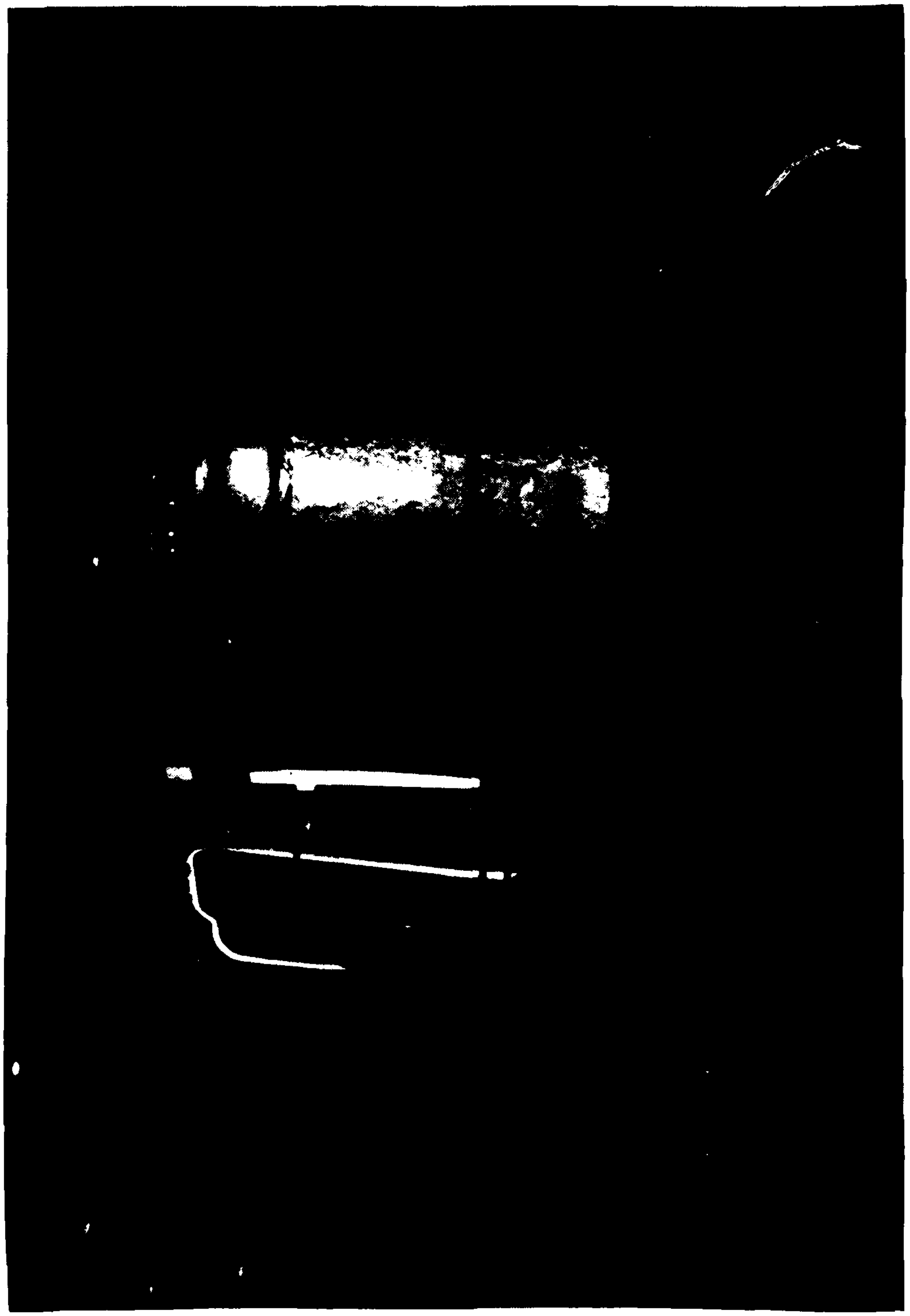


Photo 1. Portable Water Ballast

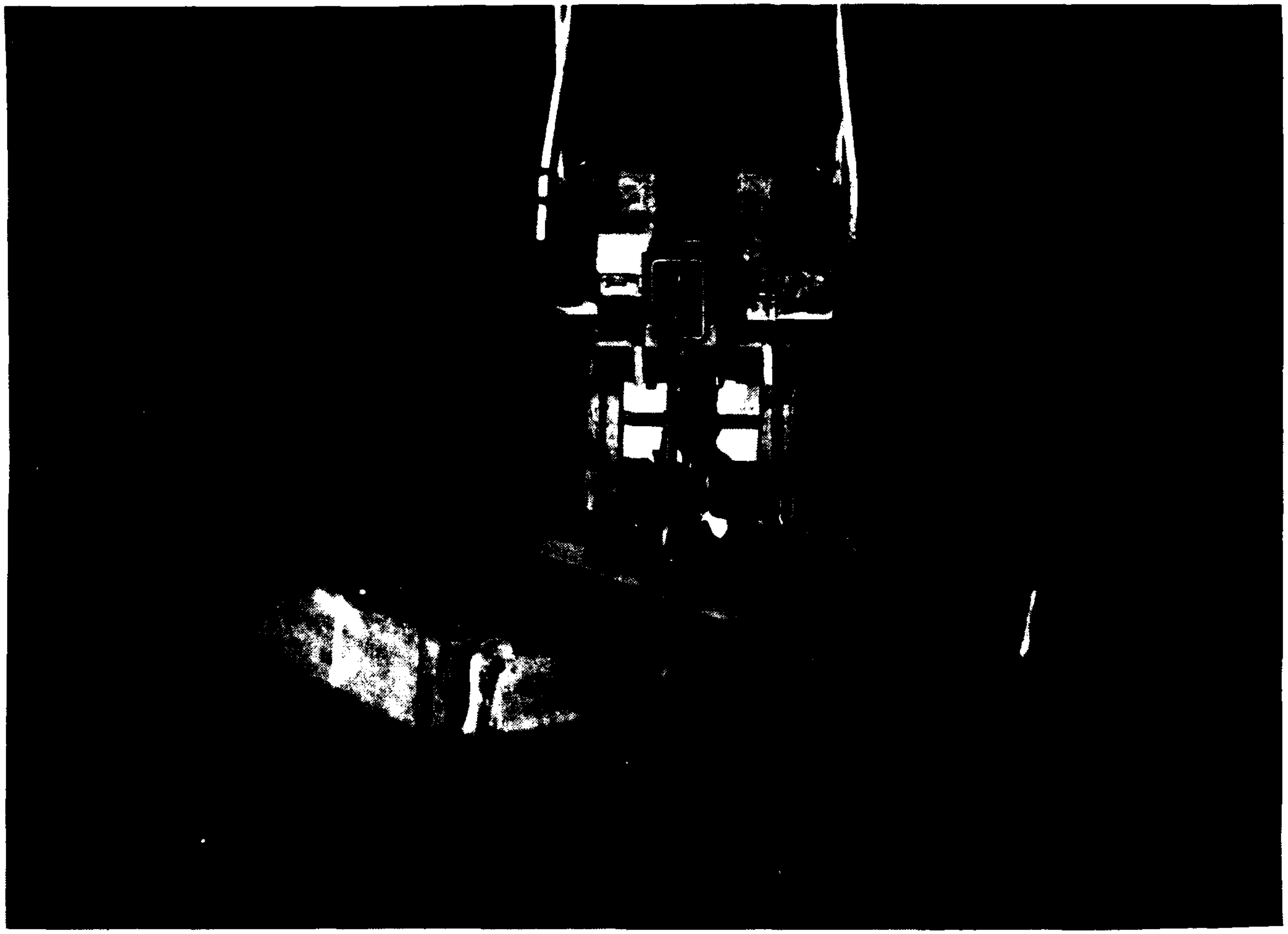
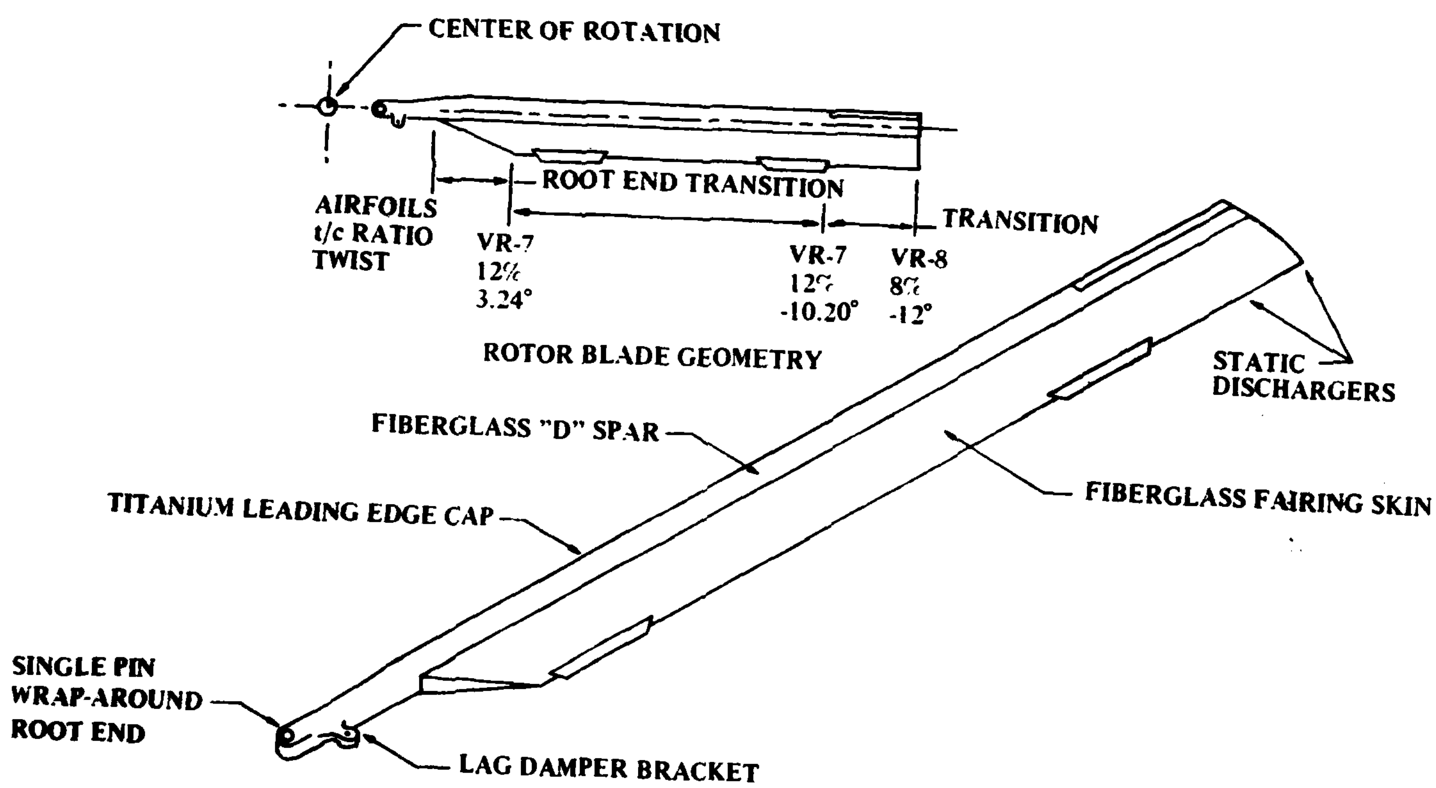


Photo 2. Movable Lead Ballast

Figure 6. YCH-47D Fiberglass Rotor Blade



8. The fiberglass rotor blades (FRB) incorporates an integral 6 element electrical deicing blanket (fig. 7). Blanket coverage extends for the full length of the titanium leading edge cap and provides for deicing capability over 3.53 inches (11 pct of chord) from the leading edge of the upper surface and 7.37 inches (23 pct of chord) from the leading edge on the lower surface. The Goodrich Company manufactured etched metal foil electrothermal heating elements start at blade Station 88.0 and extend to blade Station 356.0 for a total length of 268.0 ±0.25 inches. The deicing blanket consists of 6 spanwise oriented heating elements and 2 return leads. Heating elements and return leads are braided copper and are positioned by means of attachment to a light carrier material (screen cloth) impregnated with resin to ensure sound bonding when cured into the leading edge assembly. Blanket braids are butt spliced to the blade cable assembly at the root end, laid into the root end slot and covered over with epoxy filler. The blade cable assembly connector is attached to the lag damper bracket. The blanket provides 27 watts/in.^{2} with 195 Vrms, 400 Hz power supplied by the generator system. Power of 13,869 watts per element on all three blades on one head are applied simultaneously.

Deice Power:

9. A 40 kilovolt amp, 3 phase, 115/200 volt alternating current generator was installed on the aft transmission. The generator is oil cooled and is the same that powers the aircraft number one and two electrical system. The new transmission was designed with provisions for the third generator. A generator control switch was located on the overhead console. A three positions switch allowed the pilot to test or turn the generator OFF or ON. An overcurrent relay was installed to protect the generator. Two lights installed in the cockpit illuminated when voltage was applied to either the forward or aft deice heating elements.

System Control and Power Distribution

10. The deice system control and power distribution unit was contained on a 3 x 5 foot wooden pallet. The pallet was mounted on the movable ballast system between station 140 and station 177 (photo 3). The basic system components mounted on the pallet included a controller, controller monitor pulse counter, lights, control switches, and relays. Lights indicated "cycle start," "cycle complete," "counter reset," "ice detect forward" and "ice detect aft" (photo 4). A duplicate set of lights was also installed in the cockpit on the lower console. The system control switch, located on the upper console, was operated by the pilot in an OFF, ON or AUTO mode. Two switches, located on the pallet, would start the deice cycle and select either the forward or aft ice detector to command the pulse counter. The controller (BV P/N 11192-1) was supplied with both 115/200 volts AC and 28 volts DC power when a 28 VDC positive ice signal was received from the pulse counter, a 200 volt, 400 hertz, 3 phase current was pulsed to the rotor blade heating elements. A controller monitor (BV P/N 11195-1) detected heater overcurrent, undercurrent, ground faults, and ensured that the distributors advanced to the next heater zone with each ON pulse. additionally, the controller monitored for unbalanced line currents, automatically latched out, removed blade heater power, and provided a caution warning in the event of a previously listed failure. A preflight built-in-test of the protective functions was also contained in the monitor. Once the deice cycle was started, current was pulsed through the first through sixth heater blankets by way of the forward rotor power transfer unit. The seventh through twelfth pulses were fed to the aft rotor power transfer unit. The controller always returned to the number one position unless the system shut down during operation.

FIGURE 7
YCH-47D FIBERGLASS ROTOR BLADE DE-ICE BLANKETS

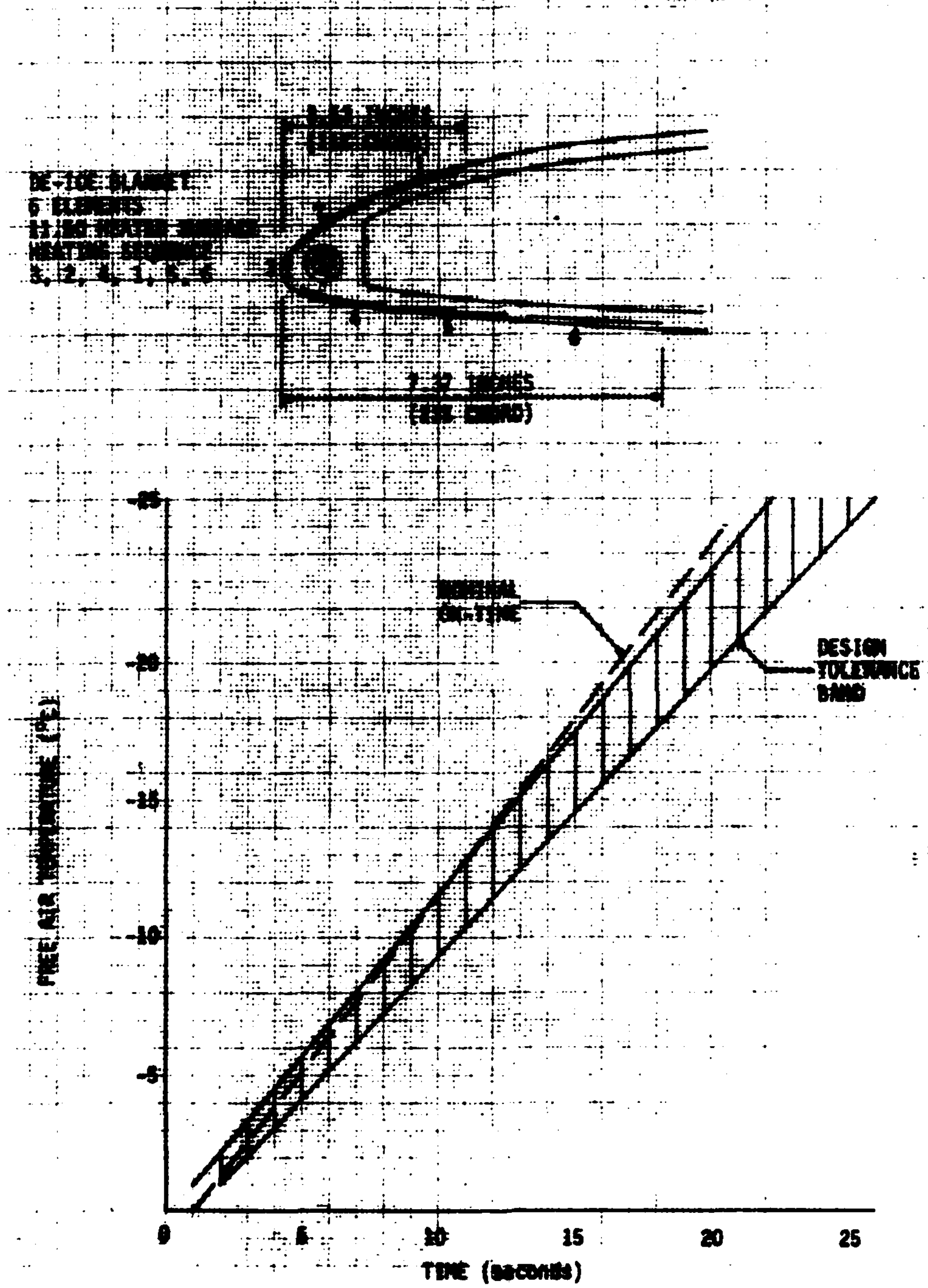


Photo 3. Deice Control Pallet

Photo 4. Deice System Indication and Control Panel

Hub Mounted Power Distribution Elements

11. Power conducted from the cabin mounted elements through the forward and aft transmission shaft standpipes was transferred to the rotating system by means of a standpipe mounted 4-brush slip ring. The slip ring provided power to a power distributor, which supplies power to each individual blade blanket through appropriate cabling. The slip ring and distributors were mounted within a closed aluminum cover to provide environmental protection (photo 5).

Ice Detection:

12. Ice detection was provided for the system through either the forward pylon or aft pylon mounted Rosemount ice detectors (photos 6 and 7). Selection of the desired detector was by means of pallet-mounted selector switch. Ice detectors were located in pylon areas chosen (based on air flow and review of previous test data) to provide required icing correlation.

Free Air Temperature (FAT) Sensor:

13. Free air temperature (FAT) sensing was provided from a FAT sensor located on the right lower fuselage approximately Station 95 forward of the forward left gear (photo 8). It provided the signal to the system control which determined the length of time each individual heater element was energized.

Cockpit Displays and Controls:

14. Cockpit displays had lights which indicated power pulses to the blades, generator failure, a forward head ice detect and an aft head ice detect. The power pulse advisory lights indicated deice cycle start, deice cycle complete, and individual rotor system deice cycle pulses (photo 9). Two control switches were located on the overhead console. The generator switch had a test position and OFF and ON. The deice system could be controlled in an automatic or manual mode. System circuit breakers were located in the cockpit.

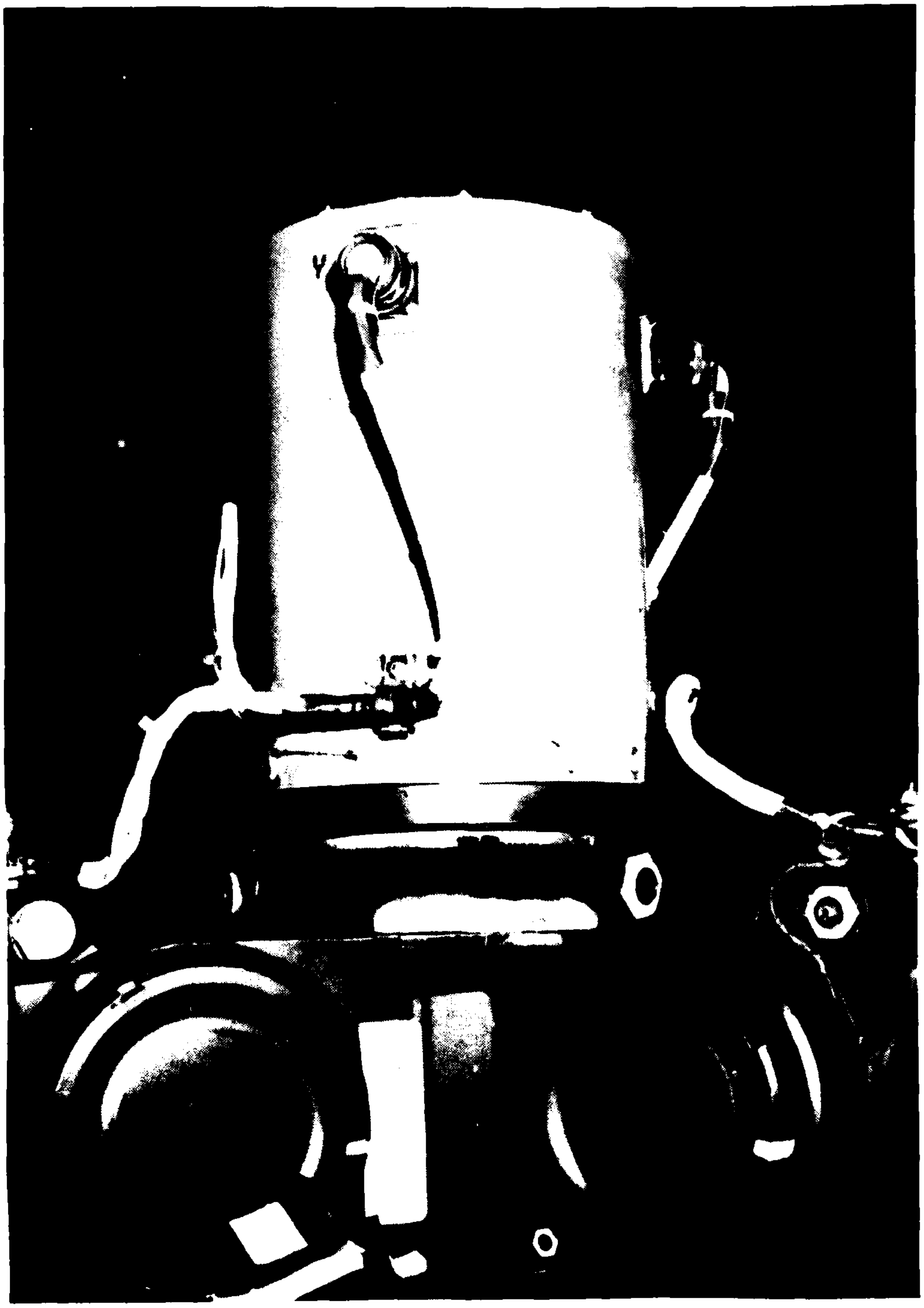


Photo 5. Power Distribution Slip Rings

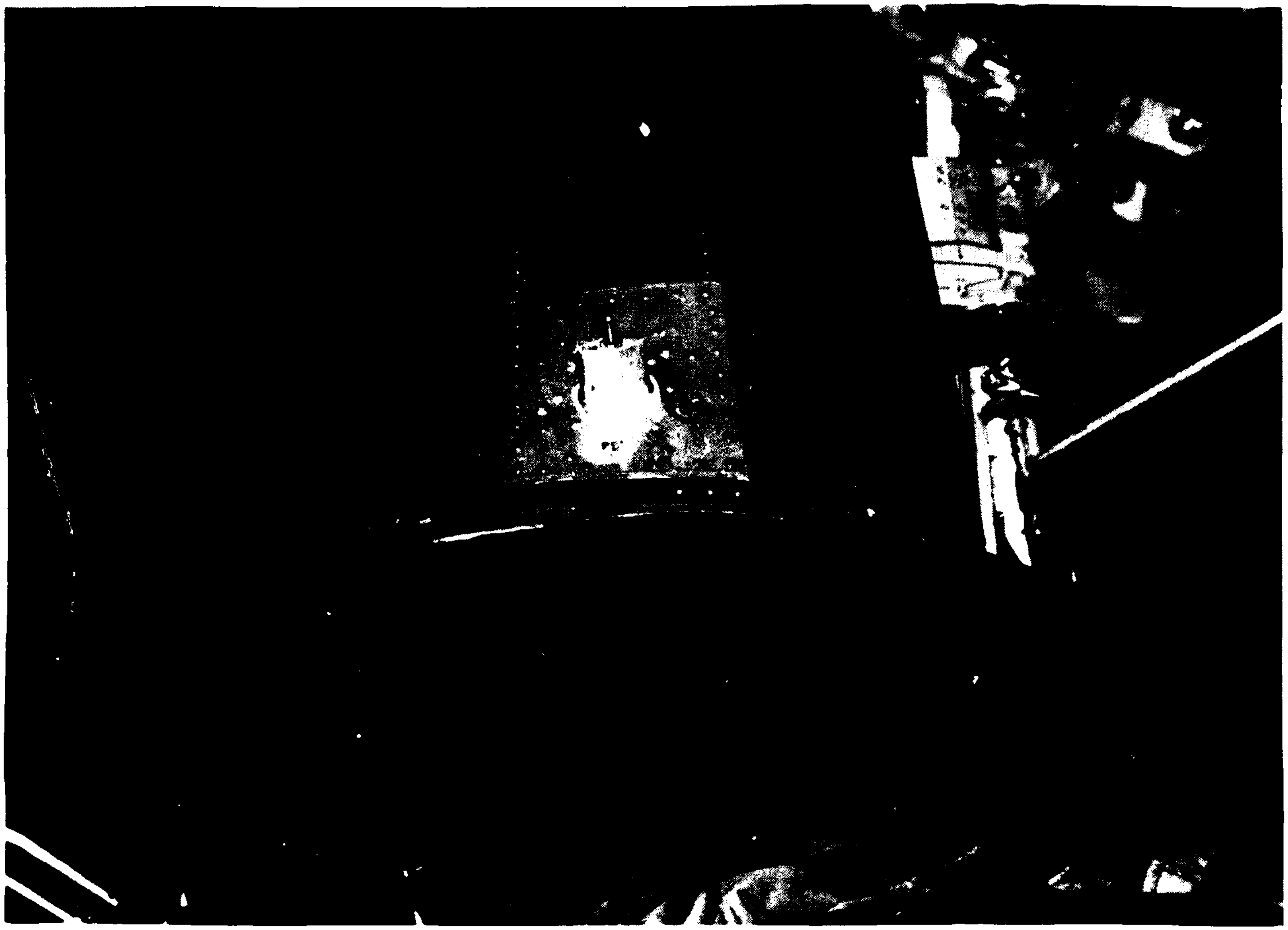


Photo 6. Forward Pylon Rosemount Ice Detector

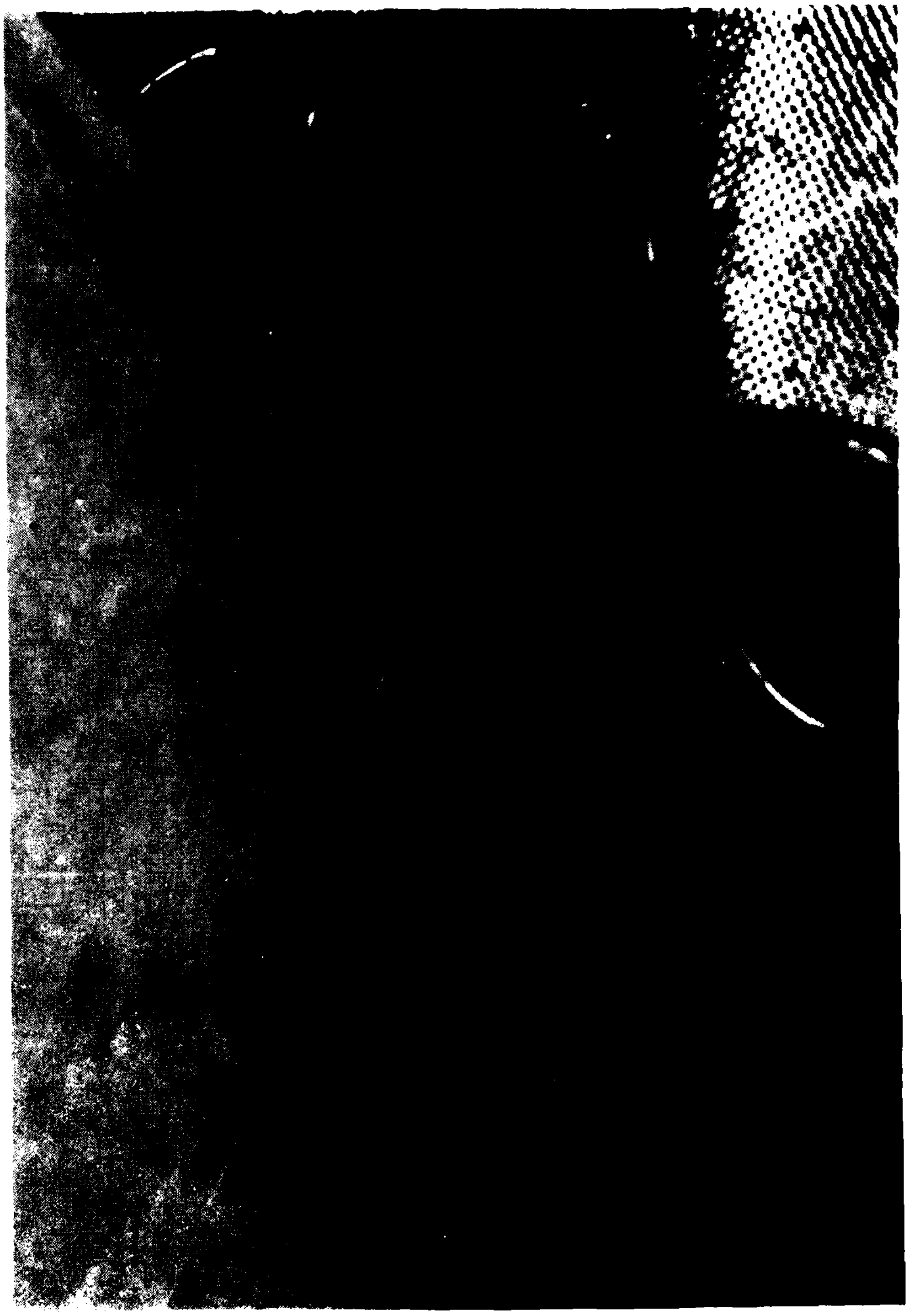


Photo 7. Aft Pylon Rosemount Ice Detector

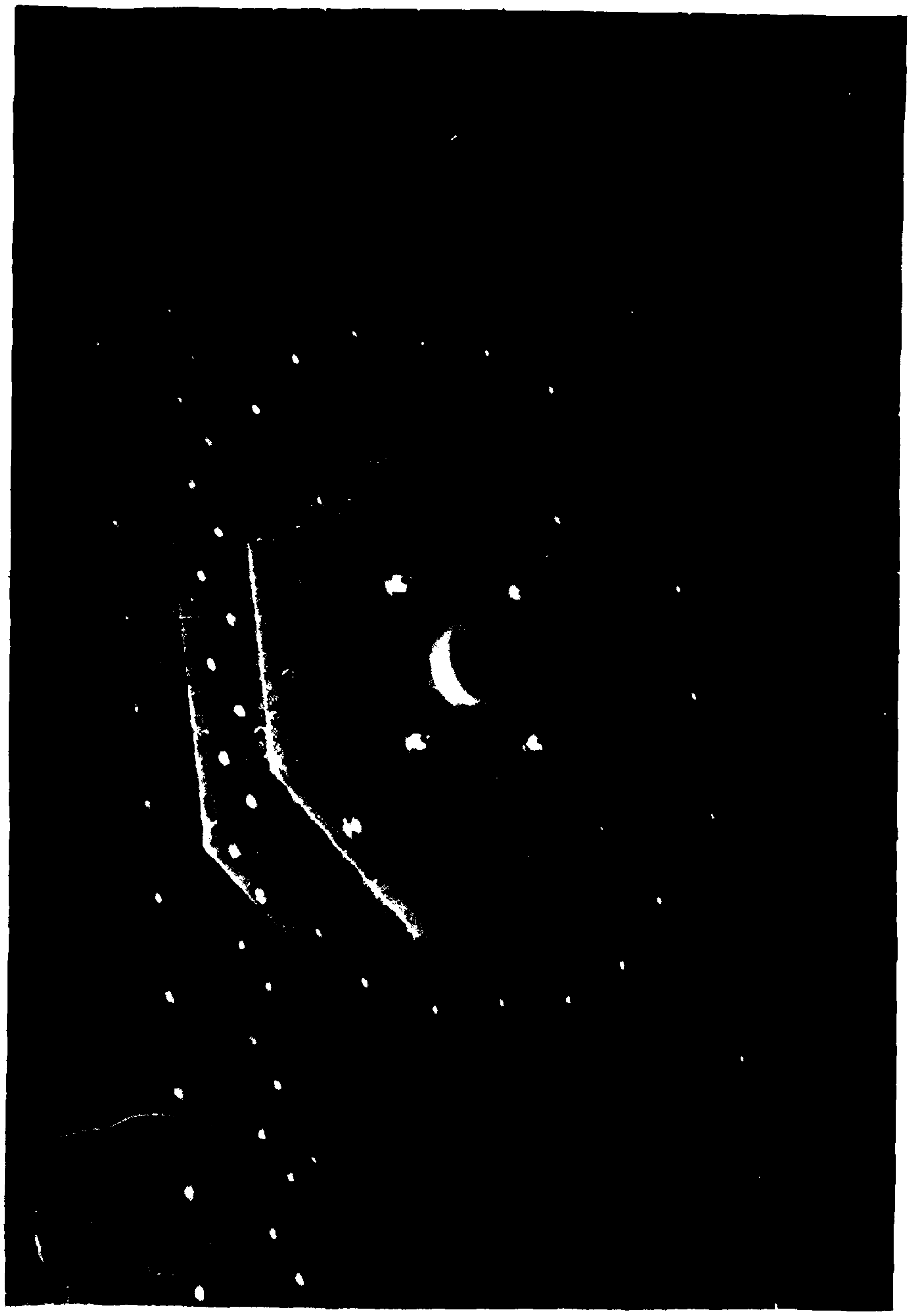


Photo 8. Underside Free Air Temperature Probe

Photo 9. Deice System Control Lights and Leigh Mark XII Control Panel

APPENDIX C. INSTRUMENTATION AND SPECIAL EQUIPMENT

INSTRUMENTATION

1. In addition to, or instead of standard aircraft instruments, calibrated test instrumentation was installed aboard the test aircraft. The instrumentation was installed and maintained by Boeing Vertol. Data were recorded by hand from cockpit instruments, and on PCM encoded magnetic tape. The instrumentation package is shown in photo 1.

2. The test instrumentation available during this program is listed below:

Pilot Station

Run number
Time of day
Event switch
Liquid water content meter (Leigh)
Rosemount deice indicator
Deice system operation indicator lights and controls

Magnetic Tape

Airspeed
Altitude (pressure)
Rate of climb
Rotor rpm
Engine torque (both engines)
Engine N_1 (both engines)
Fuel flow (both engines)
Fuel temperature (both engines)
Longitudinal stick position
Lateral stick position
Directional control position
Collective stick position
Pitch attitude
Roll attitude
Yaw attitude
Pitch rate
Roll rate
Yaw rate
Time code
Event pulse
Cruise guide voltage
Vibration
  Station 50 (2 vertical pilot and copilot seats)
  Station 95 (3 axis)
  Station 360 (3 axis)
  Station 585 (3 axis)
Outside air temperature
Liquid water content (Leigh)
Rotor deice voltage (3)
Rotor deice current (3)
Rosemount icing rate (fore and aft detectors)
Rotor blip

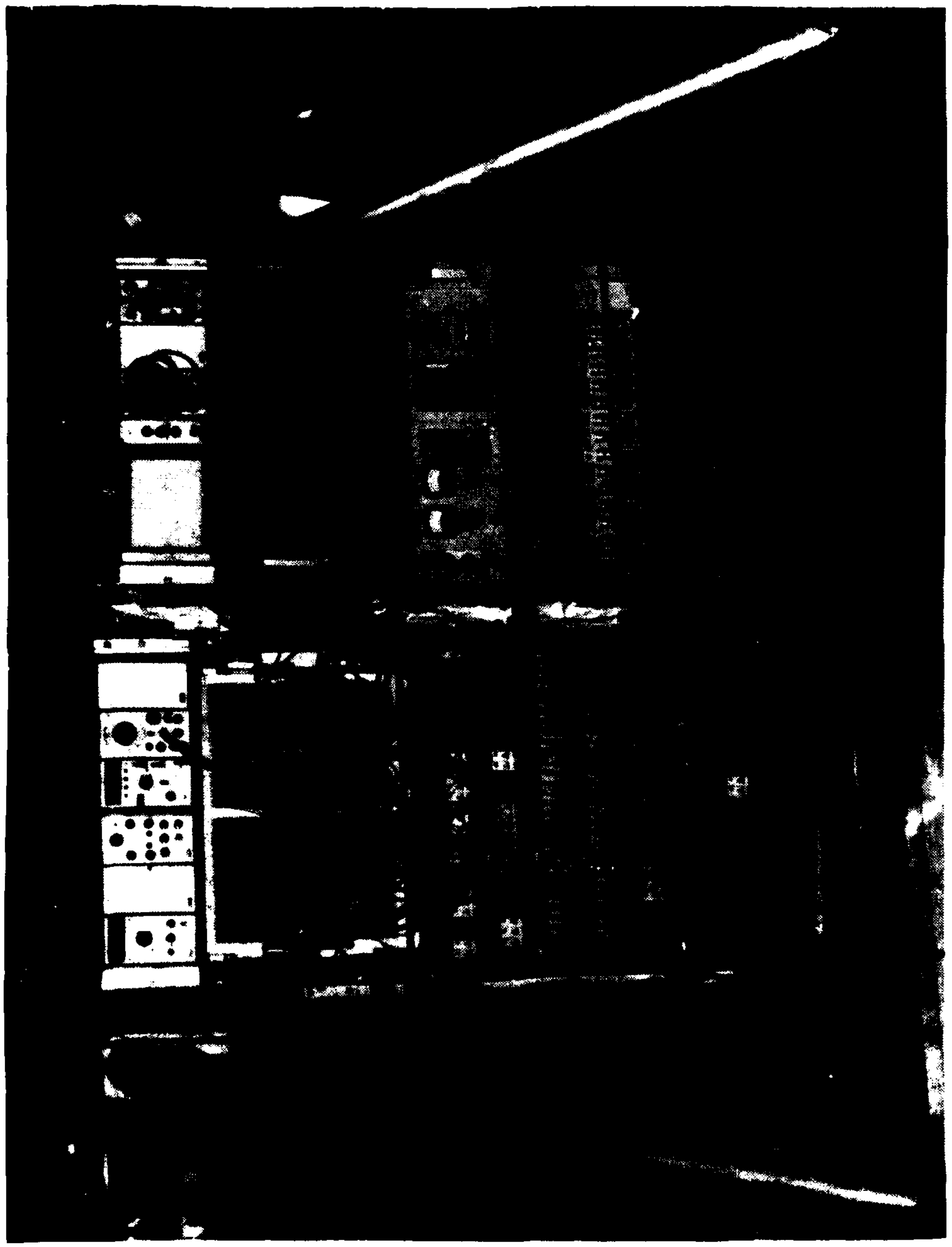


Photo 1. Instrumentation System

SPECIAL EQUIPMENT

Rosemount Ice Detector

3. Two Rosemount Model 871FA nonaspirated ice detectors were mounted on the aircraft; one each on the left side of the fore and aft pylons (photos 5 and 6, app B). Each detector measured accreted ice to a depth of 0.02 inches on the probe. At that point, the probe deiced and a new cycle began. With the blade deice system in the automatic mode, either of the Rosemount detectors could be chosen to activate the system after three probe deice cycles. Cockpit indication consisted of lights showing when the probe was being deiced.

Leigh Ice Detector

4. A single Leigh Ice Detector Unit, Mark XII (IDU-3) was mounted on the right side of the forward pylon (photo 2). As with the Rosemount probe, ice accreted to a preset level, then the probe deiced. The deice cycles are timed and the rate of accretion is calibrated in terms of LWC. The cockpit indication is a gage showing ice severity (photo 9, app B). The gage is divided into four zones:

Zone	Severity	Color	LWC
1	Trace	White	0 - 0.05 gm/m^3
2	Light	Green	0.05 - 0.5 gm/m^3
3	Moderate	Yellow	0.5 - 1.0 gm/m^3
4	Heavy	Red	1.0 - 2.0 gm/m^3

A calibration of the LWC corrected for airspeed is shown in figure 1.

Visual Ice Indicators

5. A visual ice accretion indicator (photo 3) was mounted on the test aircraft to give the pilot a visual cue of ice buildup on the helicopter. It was composed of a small symmetrical air foil (OH-6A tail rotor blade section) with a 3/16-inch diameter steel rod protruding 1-1/2 inches out from the leading edge at the center. The protruding rod was painted with multi-colored 0.2-inch stripes to provide a reference for ice thickness estimation. The unit was mounted on the pilot's door facing forward.

6. Outside the left window was a "V" shaped linear ice accretion meter known as the "Harvey Smith" indicator (photo 15, app E). The copilot sighted the device in such a way that the apex of the "V" was at zero on the calibrated scale. The ice depth was read on the scale at the point where the accreted ice on one leg of the "V" crossed the vernier scale on the other leg. A calibration chart was used to determine LWC from the indicated icing rate (mm/min) and airspeed (fig. 2).

Photographic Equipment

7. A still camera was mounted just aft and to the right of the forward pylon. Activated from the instrumented rotor blip through an intervelometer, the camera took pictures of one of the aft rotor blades during flight (photo 4).

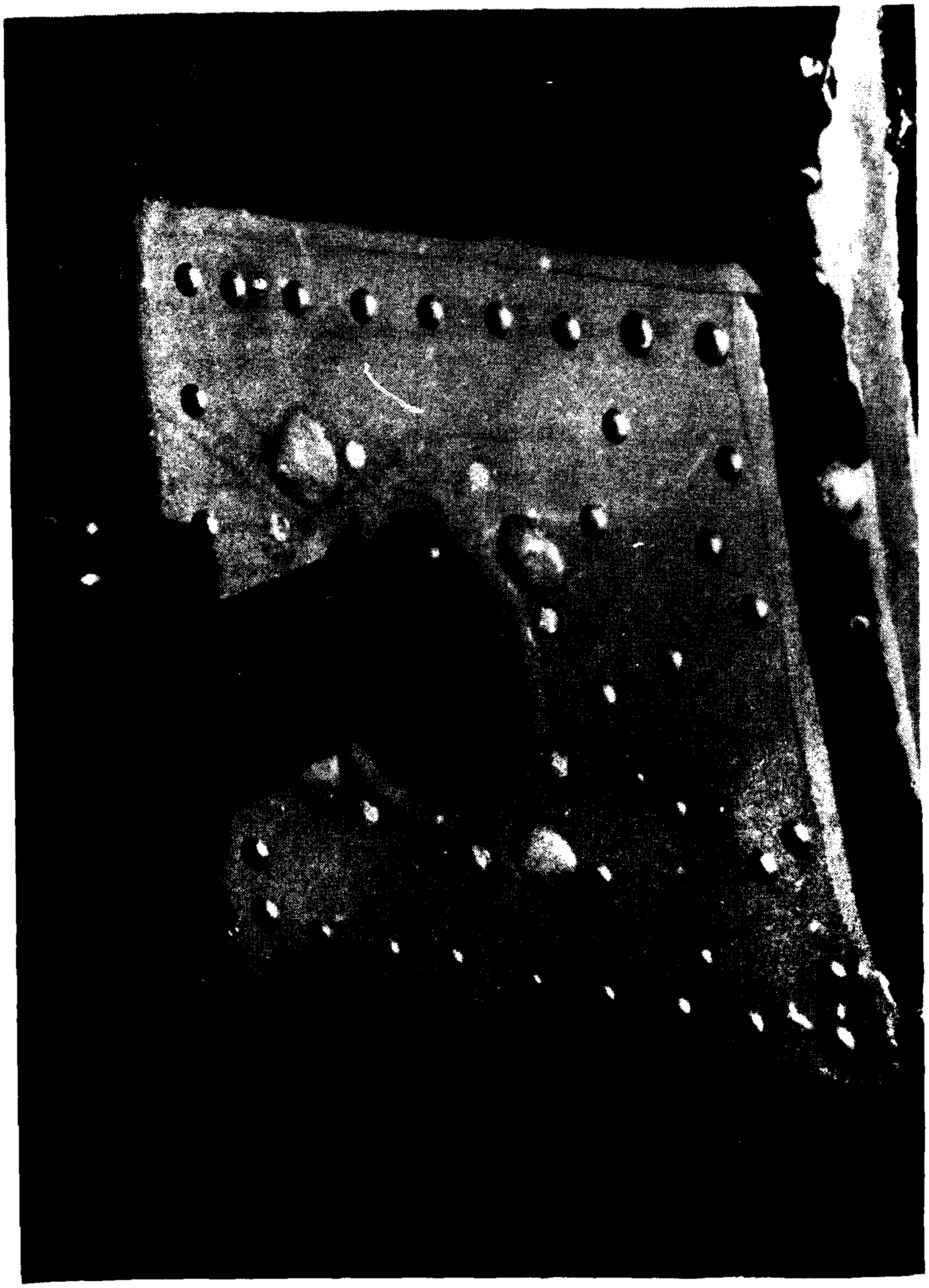


Photo 2. Forward Pylon Leigh Mark XII Ice Detector

FIGURE 1
[illegible]-3 DETECTOR CALIBRATION

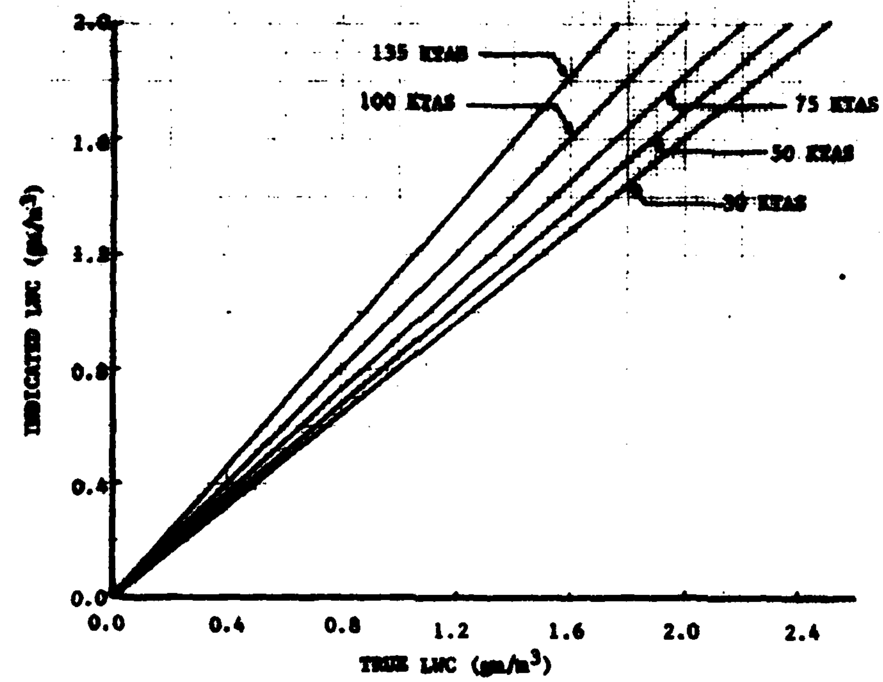


Photo 3. Visual Ice Accretion Indicator

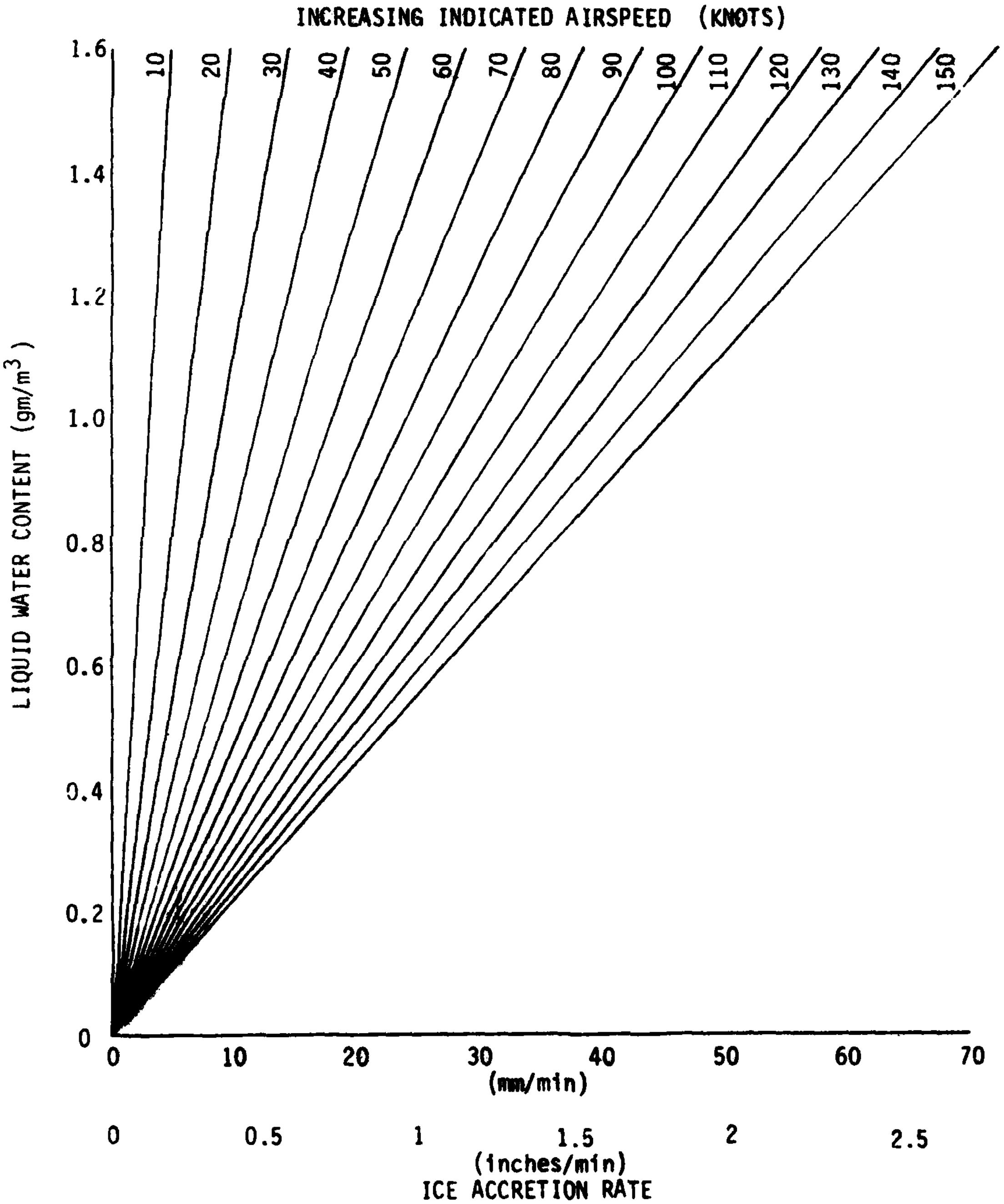
FIGURE 2

BRITISH LINEAR ICE ACCRETION METER
"HARVEY SMITH"

LIQUID WATER CONTENT CALIBRATION CHART

NOTE: 1. CALIBRATION IS BASED ON 100 PERCENT CATCH EFFICIENCY

2. FREEZING FRACTION (UNITY)



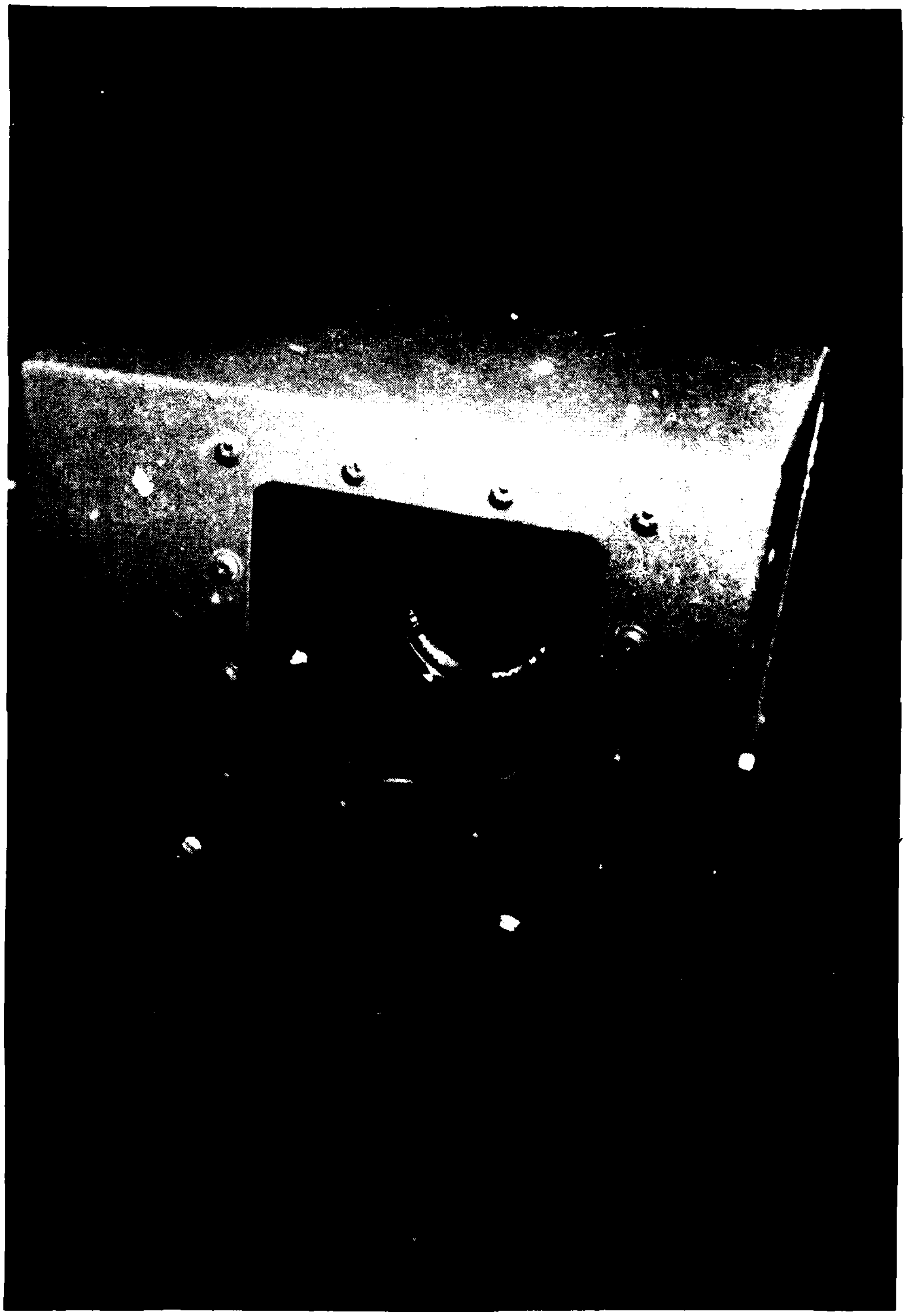


Photo 4. Still Camera Synchronized to Aft Rotor Blade

8. Two fiber optic television cameras were installed on the number 2 engine inlet. One lense was focused on the underside of the inlet screen at the 11 o'clock position. The other focused on the engine "D" ring at the 12 o'clock position (photo 5). A video monitor and tape recorder were mounted in the cabin area (photo 6).

Photo 5. Fiber Optic TV Camera

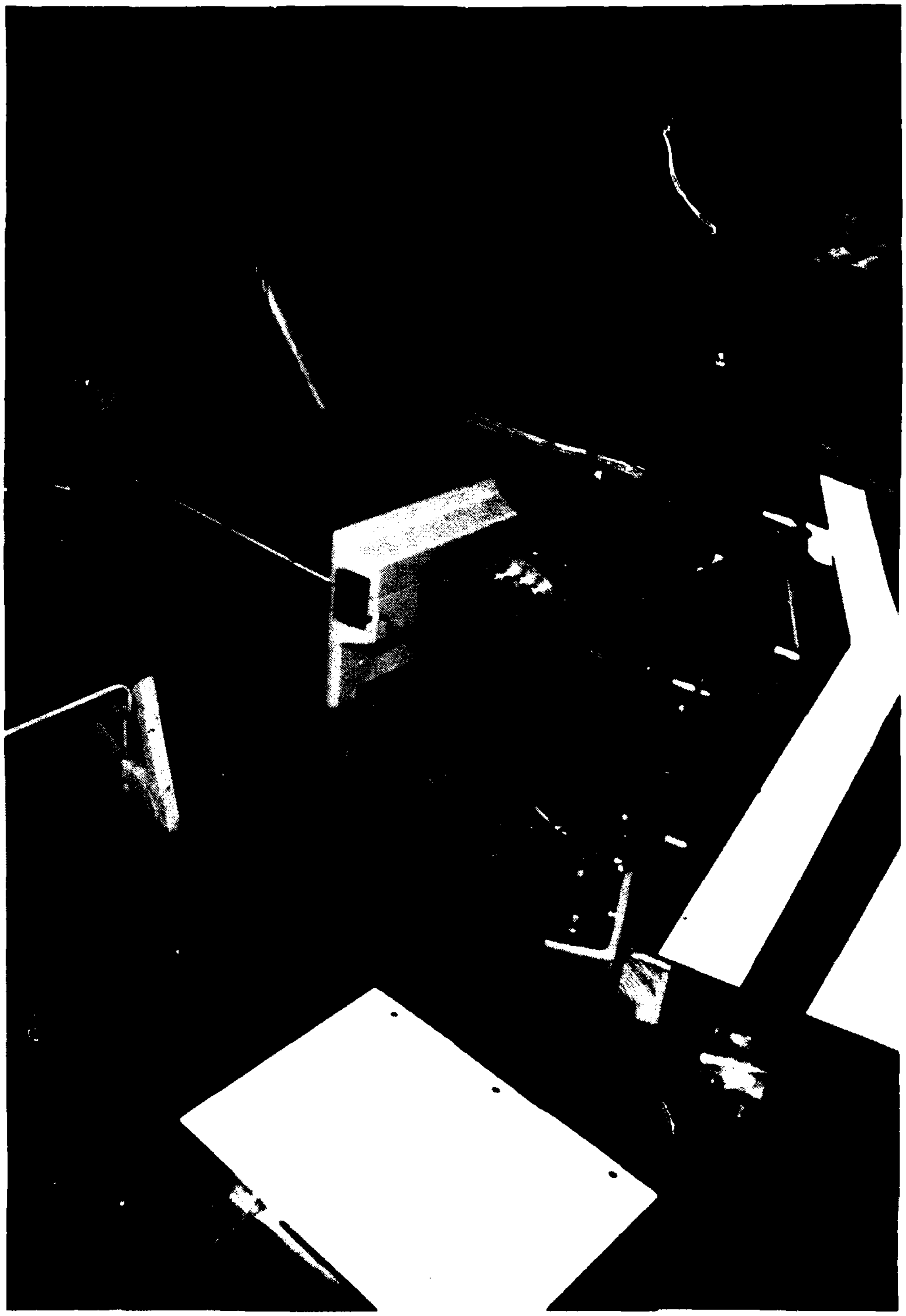


Photo 6. Video Monitor and Recorder

APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

GENERAL

1. The YCH-47D is a prototype version of an improved CH-47, equipped with a "test" deicing system. A CH-47C with FRB and a "breadboard" deice system was tested previously (ref 1, app A) and corrections for deficiencies noted in that test were applied to the YCH-47D. The YCH-47D test was conducted in two phases: the first phase (heated rotor blades), was conducted behind the HISS with the deice system operational; the second phase (unheated rotor blades) was conducted with the deice system in a STANDBY mode in both artificial and in natural icing conditions. The data was recorded continuously on magnetic tape with event markers used when significant events occurred. Photographs were taken on a regular basis by the synchronized camera mounted on top of the aircraft focused on one aft rotor blade, by a hand-held camera inside the YCH-47D, and by photographers in both the chase and HISS aircraft. On landing, photographs and a measurements of all ice buildups were made.

2. All test flights in phase I, with heated rotor blades, were conducted to: (a) establish proper functioning of the deice system; and (b) to insure blade ice could be removed in the event of an asymmetric shed. All functional checks of anti-ice and deice systems were made enroute to the test area. When the HISS was established at the target FAT airspeed, and LWC, the test aircraft moved into the cloud from below at approximately 150 feet behind the spray aircraft. Distance from the HISS was determined by the HISS's aft facing radar altimeter and relayed to the crew of the test aircraft. Initially, the ice detectors on the forward pylon were immersed in the cloud to determine LWC then each rotor head was immersed twice in the cloud during the flight. The first immersion was made with the rotor deice system in the AUTOMATIC mode. After the forward head had been immersed for three deice cycles, the aft head was placed in the cloud for three deice cycles to evaluate the effect of icing conditions on the aft rotor, the transmission oil cooler inlet and engine inlets. The second immersion was made to insure that large ice buildups on the rotor blades could be removed with the deicing blankets. The rotor deice system was left in the STANDBY mode and each rotor was immersed for time equivalent to the three deice cycles. Upon completion of the immersion of each, rotor, the deice system was manually activated to deice the blade. High speed motion pictures were taken to establish proper functioning of the deice system in shedding the ice. The system was considered operational for flights in the natural environment after the first three flights using the techniques above. The aircraft time in the cloud was usually limited by the HISS water supply.

3. Phase II, with unheated rotor blades, began after Phase I had established that all deice and anti-ice systems were functioning properly. These flights were conducted in artificial or into known or predicted natural icing conditions. When instrument meteorological conditions (IMC) existed, an instrumented flight plan was filed and the flight conducted under the positive control of the Minneapolis Approach Facility. A vertical sweep of the cloud mass was made to determine the altitude of the highest LWC within the mass. The balance of the flight was then conducted at that altitude and a constant airspeed. The flight was terminated because of low fuel or diminishing icing conditions. Chase aircraft requirements were determined on a flight-by-flight basis, with the chase aircraft initially launching into visual meteorological conditions (VMC) in the vicinity of the test aircraft. As confidence in the system developed, the chase aircraft remained on the ground in a standby status. Two flights were launched into reported icing conditions which

changed to heavy snow. The flights were continued in these conditions to investigate the results of snow on the engine inlet areas.

4. The flights were made with number two engine anti-ice OFF, except for two flights in natural icing when the number one engine anti-ice was OFF and number two system was ON. Engine ice accretion was monitored in flight using a fiber-optic system and an on-board television camera with a video tape recorder attached. A light source was relayed through one strand of the optical fiber to illuminate the underside of the number two engine inlet screen and engine "D" ring. Two video fibers and cameras monitored any ice buildup during flight. A split screen display of the two areas provided real time information to the crew. Pictures of the outside of the engine inlet screen were also taken during flight through the davit hole on the right rear roof of the cabin. Further documentation was made on postflight inspections.

5. External ice accretion was monitored in flight using the two Rosemount detectors; a small airfoil, and a linear ice accretion meter (Harvey Smith detector) mounted outside the pilot's windows. On landing, the major external ice accretions were measured and recorded.

6. Total accumulation was calculated using the data recorded on magnetic tape from two Rosemount detectors. The detectors recorded ice accretion by changing the frequency of the sensing probe with ice buildup. When the buildup reached approximately 0.02 inches, the probe would automatically deice and the cycle would start over. A time history of the frequency changes and deice cycles was made from which the icing rate was determined over representative time periods. Total ice accumulation was then calculated using the average rate of the entire immersion time. The data presented reflects only averages, however, large deviations were noted in flight.

7. The Leigh Mark XII ice detector unit was used to measure liquid water content. LWC corrected for airspeed was computed using the calibration provided by the manufacturer.

POWER CALCULATION

8. Engine shaft horsepower was calculated from fuel flow using equations provided by BV.

$$SHP = 840 + 2.4\,((W_f/\delta\theta^{.712}) - 800) \quad \delta\theta^{.587}$$

Where:

SHP = Engine power, per engine (shp)
W_f = Fuel flow (lb/hr)
δ = Pressure ratio
θ = Temperature ratio

PHOTOGRAPHIC ANALYSIS

9. A 35mm Canon F-1 camera was synchronized with one aft rotor blade. Time sequenced black and white pictures were taken on 400 ASA film and developed using standard techniques. A scanning microdenistometer was used to measure the translucence of the negatives at each point along a 50 micron sampling grid. A digitization process converted the visual image into a two dimensional matrix of brightness values which can then be operated upon by a computer.

To determine percent ice coverage from the images, it was necessary to differentiate between background clouds, blade without ice, and blade covered with ice. Each picture element (pixel) within the digital image was classified into one of the above four groups on the basis of its brightness value. This classification was performed by displaying the digital image on a television monitor and examining each brightness value to determine whether it was a background cloud, blade without ice, or blade with ice. Note that the ice ends abruptly at about 3/4 span of the blade from the hub. This was done purposely because the outboard 1/4 of the negatives were out of focus and therefore, excluded in all calculations.

VIBRATION CHARACTERISTICS

10. Helicopter vibrations were evaluated throughout the test. The pilots made a qualitative evaluation and determination of vibrations created by asymmetric shedding. A vibration rating scale (VRS) (fig. 1) was used to augment pilot comments relative to vibrations.

WEIGHT AND BALANCE

11. The weight and balance of the test aircraft was determined at the BV plant after all airframe modifications and instrumentation changes were completed. Loading configuration changes were made using lead blocks and water for ballast.

DEFINITIONS

12. Icing characteristics were described using the following definitions of icing types and intensity. The icing intensity definitions are those used in global weather forcasting.

a. Icing type definitions:

Rime Ice	Opaque ice formed by the instantaneous freezing of small super-cooled water droplets.
Clear Ice	Clear or transluscent ice formed by the relatively slow freezing of large super-cooled water droplets.

b. Icing Intensity:

Trace	The presence of ice is perceptible on the airframe and the rate of accretion is low (LWC 0.0 to 0.1 gm/m^3).

Figure 1. Vibration Rating Scale

DEGREE OF VIBRATION	DESCRIPTION[1]	PILOT RATING
No vibration		0
Slight	Not apparent to experienced aircrew fully occupied by their tasks, but noticeable if their attention is directed to it or if not otherwise occupied.	1 2 3
Moderate	Experienced aircrew are aware of the vibration but it does not affect their work, at least over a short period.	4 5 6
Severe	Vibration is immediately apparent to experienced aircrew even when fully occupied. Performance of primary task is affected or tasks can only be done with difficulty.	7 8 9
Intolerable	Sole preoccupation of aircrew is to reduce vibration level.	10

[1] Based upon the Subjective Vibration Assessment Scale developed by the Aeroplane and Armament Experimental Establishment, Boscombe Down, England.

Light	Ice accumulation is evident on the aircraft with a rate of accumulation somewhat greater than trace icing (LWC 0.1 to 0.5 gm/m^3).
Moderate	The rate of accretion of ice on the airframe is noticeable and easily exceeds the rate of sublimation (LWC 0.5 to 1.0 gm/m^3).

13. Results were categorized as deficiencies or shortcomings in accordance with the following definitions:

Deficiency: A defect or malfunction discovered during the life cycle of equipment that constitutes a safety hazard to personnel; will result in serious damage to the equipment if operation is continued; indicated improper design or other cause of an item or part, which seriously impairs the equipment's operational capability.

Shortcoming: An imperfection or malfunction occurring during the life cycle of equipment, which should be reported and which must be corrected to increase efficiency and to render the equipment completely serviceable. It will not cause an immediate breakdown, jeopardize safe operation or materially reduce the usability of the material or end product. If occurring during test phases, the shortcoming should be corrected if it can be done without unduly complicating the item or inducing another undesirable characteristic such as increased cost, weight, etc.

APPENDIX E. PHOTOGRAPHS

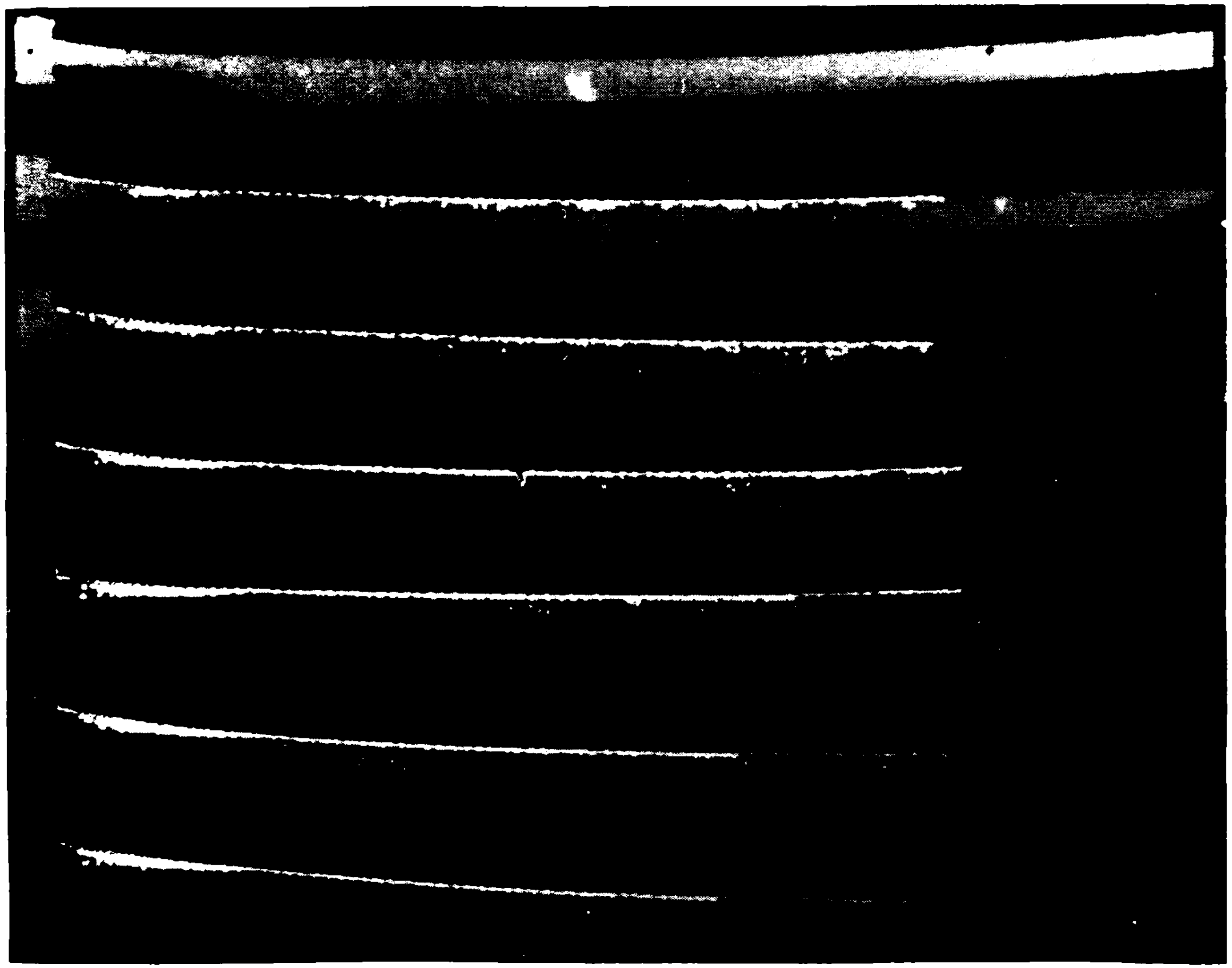


Photo 1 of 3. Natural Ice on Aft Rotor Blade at 2½-Minute Intervals - Flight 4

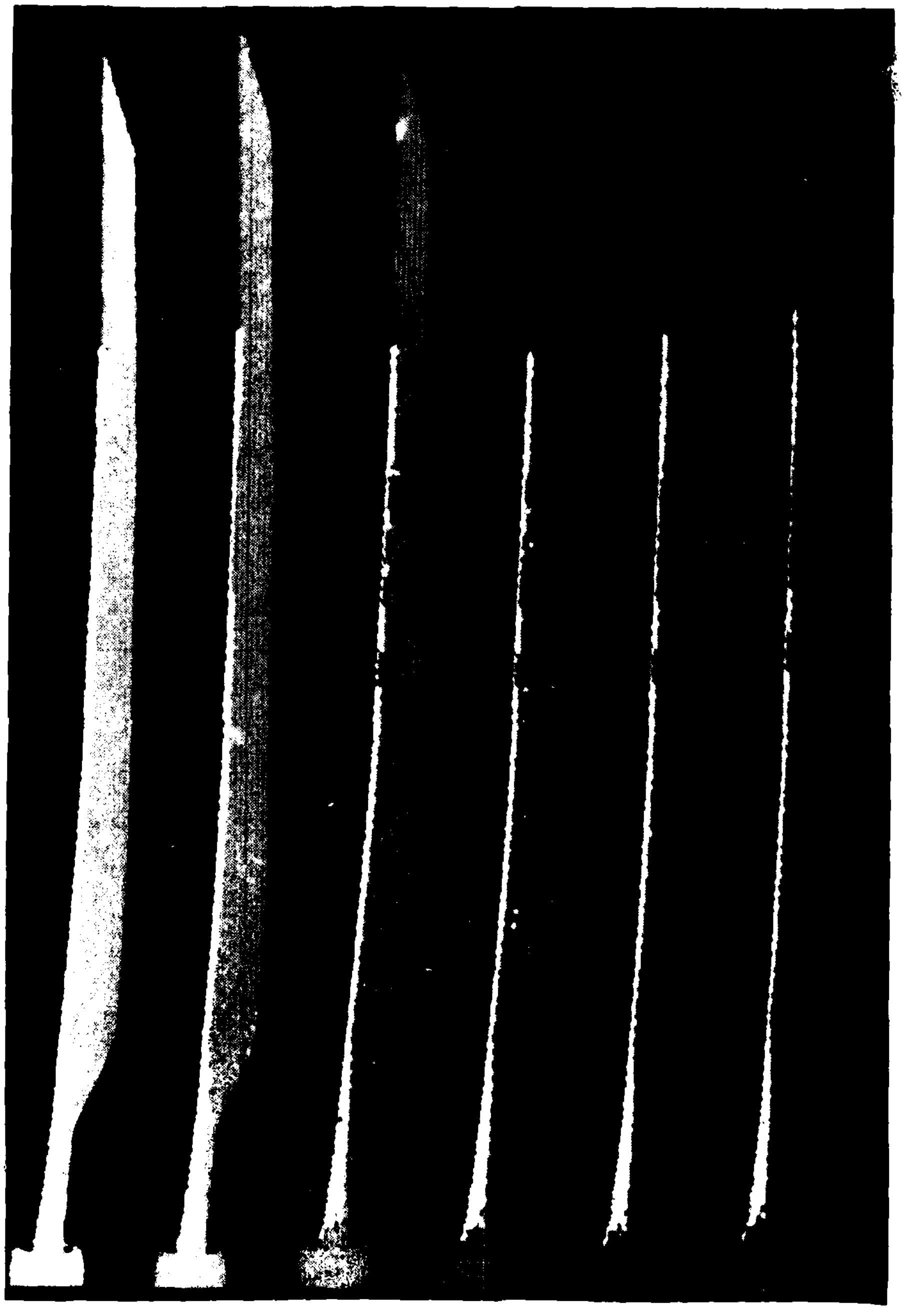


Photo 2 of 3. Natural Ice on Aft Rotor Blade at 2½-Minute Intervals - Flight 4

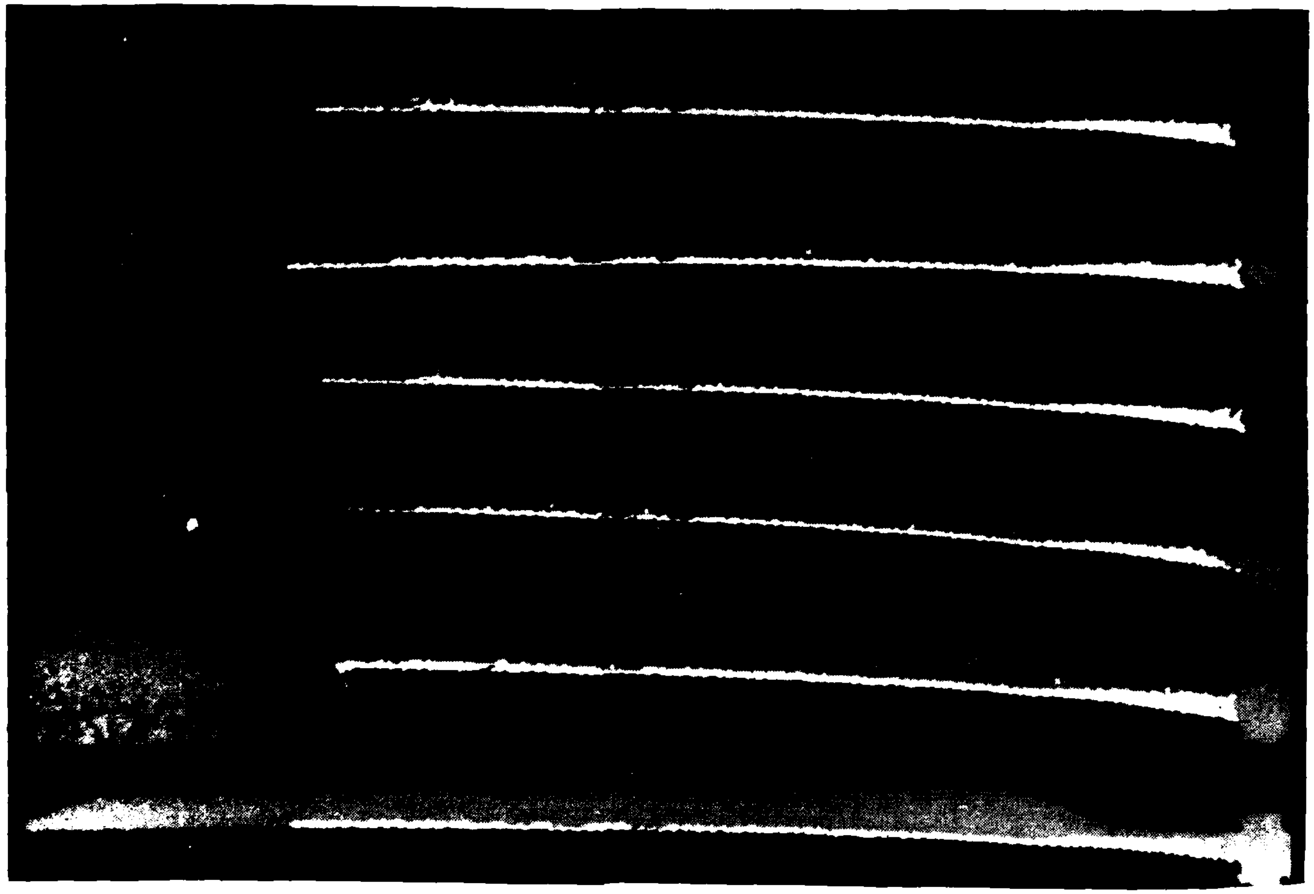


Photo 3 of 3. Natural Ice on Aft Rotor Blade at 2½-Minute Intervals - Flight 4

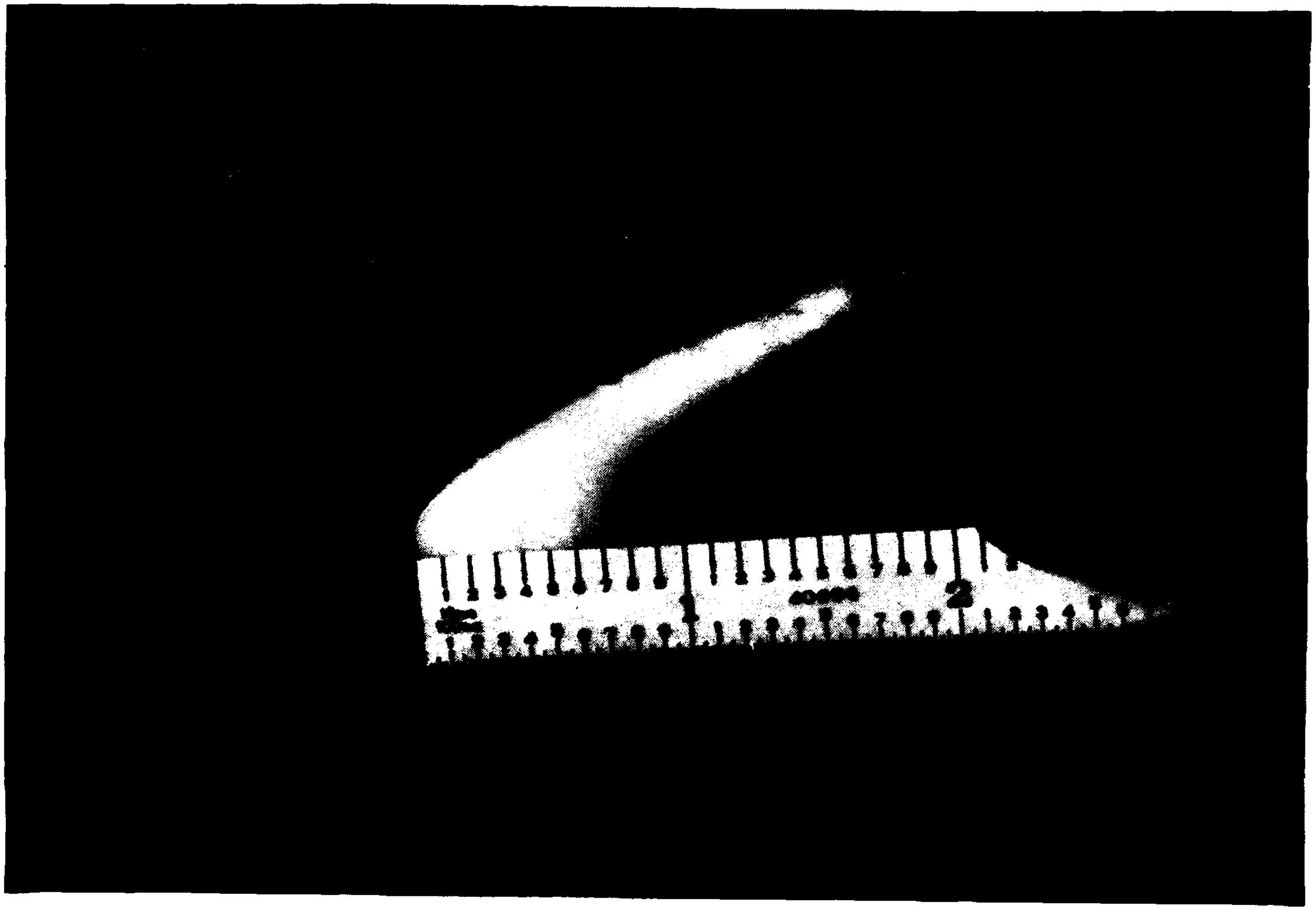


Photo 4. Ice from Blade Station 120 - Flight 4

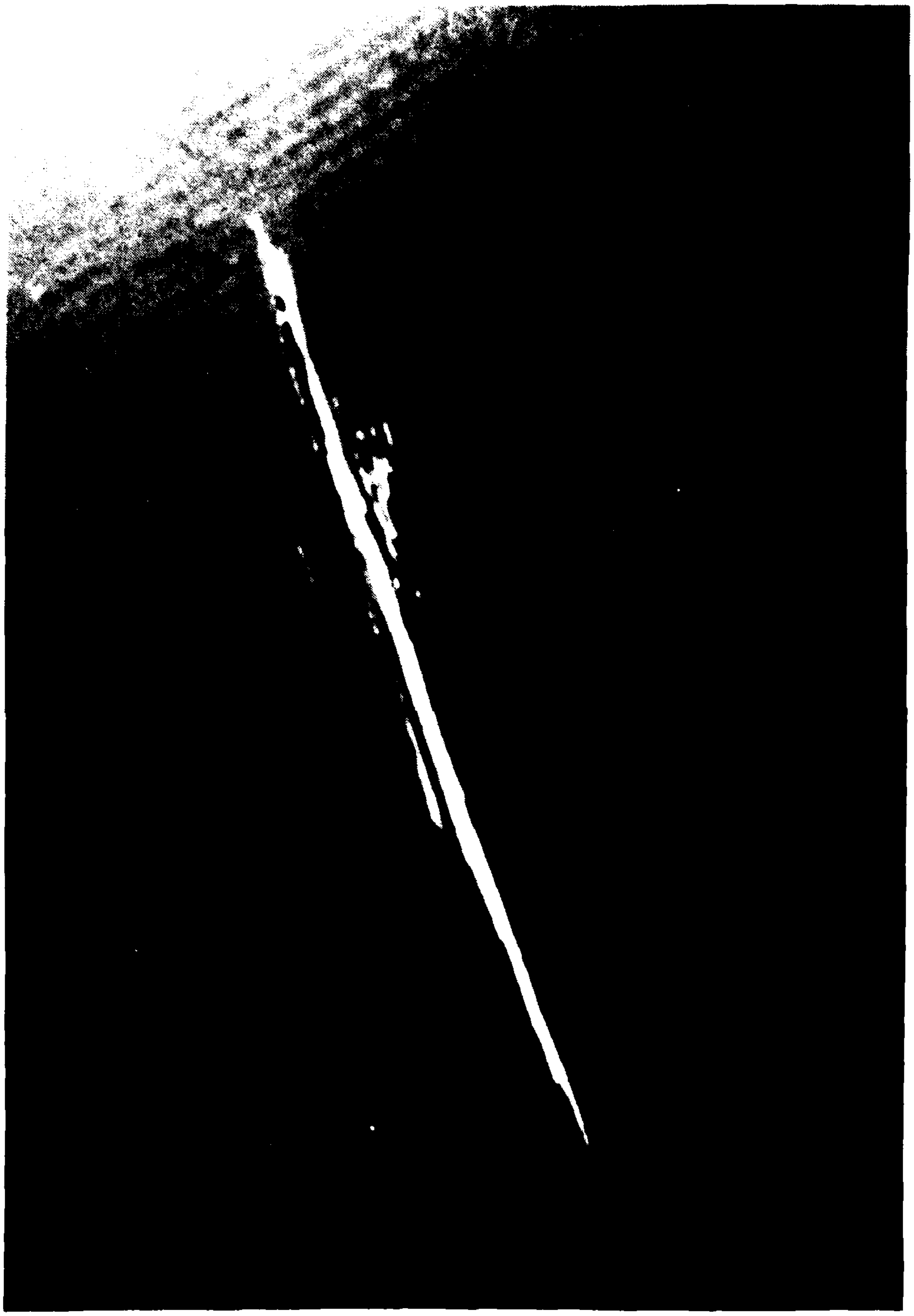


Photo 5. Forward Yellow Blade Delamination - Flight 6

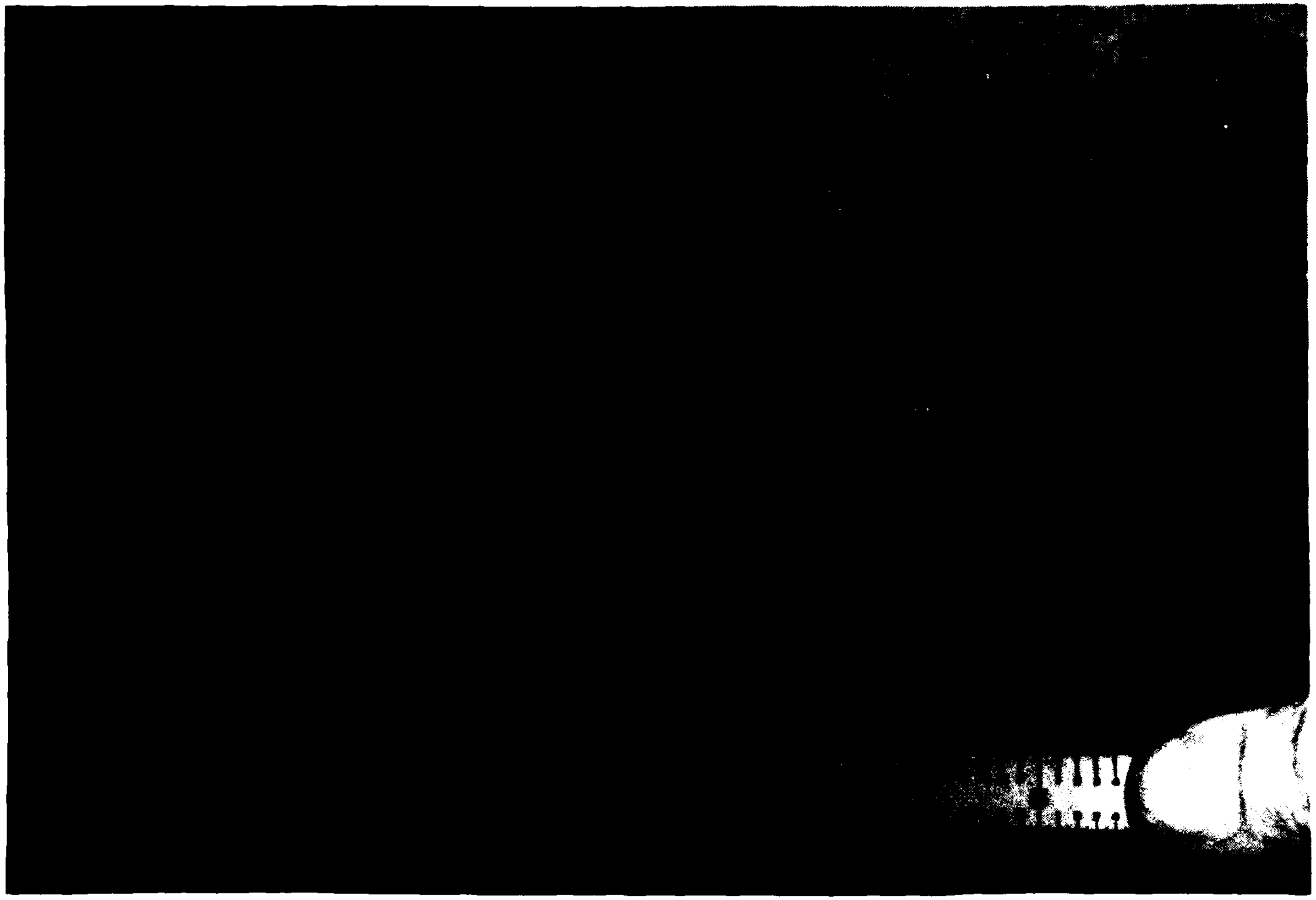


Photo 6. Repair of Aft Yellow Blade Delamination - Flight 10

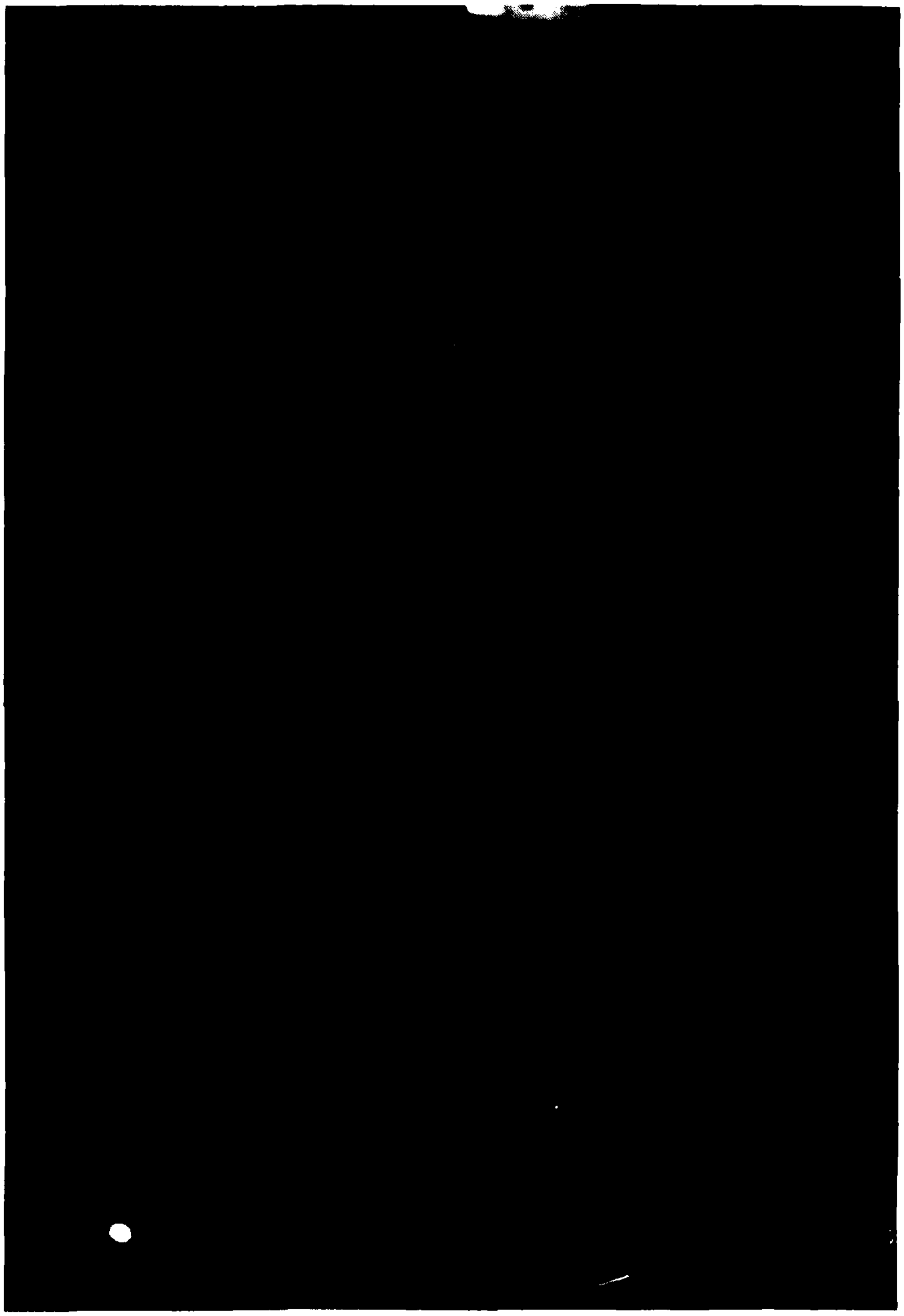


Photo 7. Blade Void from Ice Impact - Flight 9

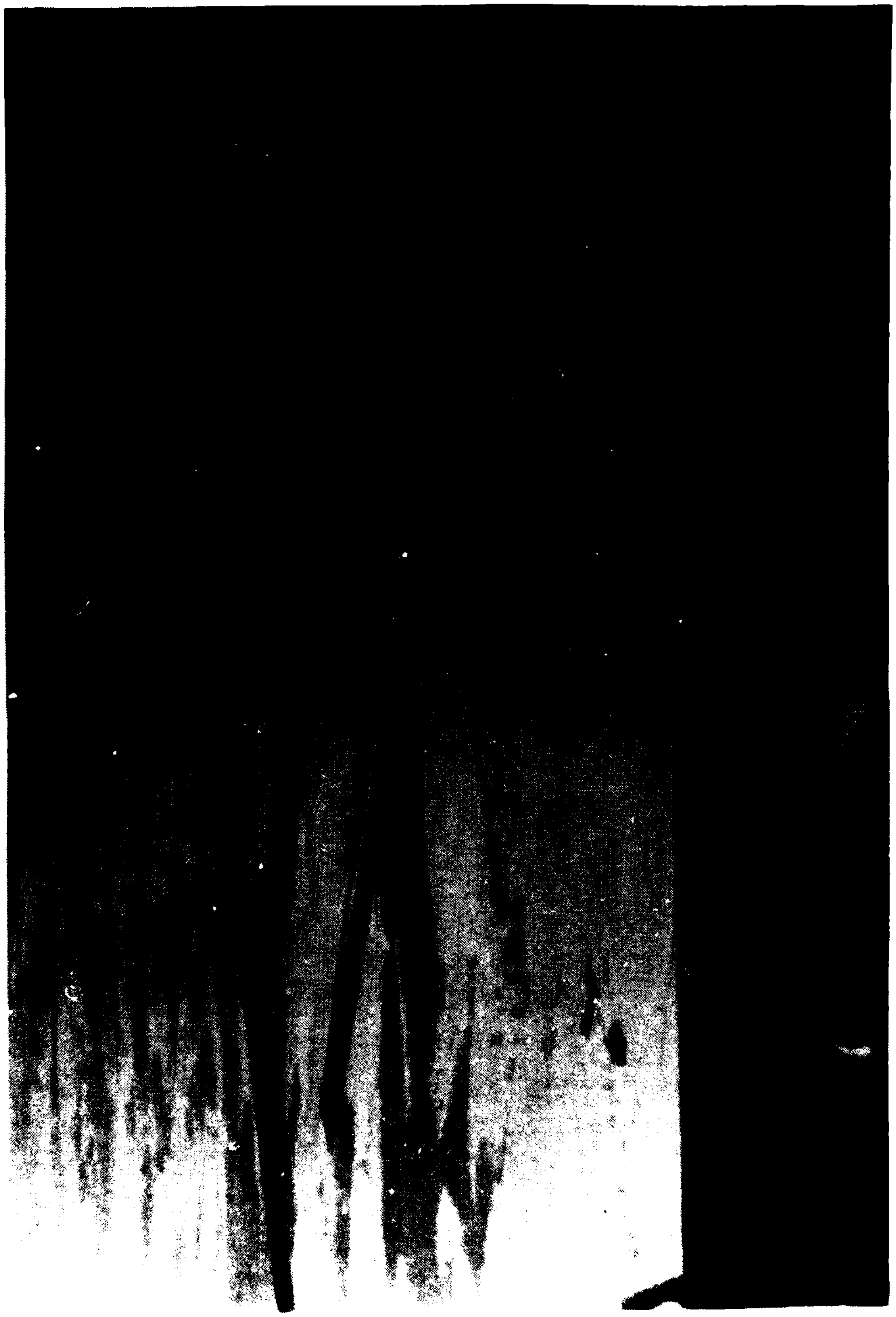


Photo 8. Ice Shed - Flight 5

Photo 9. Ice Shed - Flight 8

Photo 10. Blade Glass Cover Delamination and Core Damage - Flight 9

Photo 11. Fiberglass Rotor Blade Repair - Flight 9

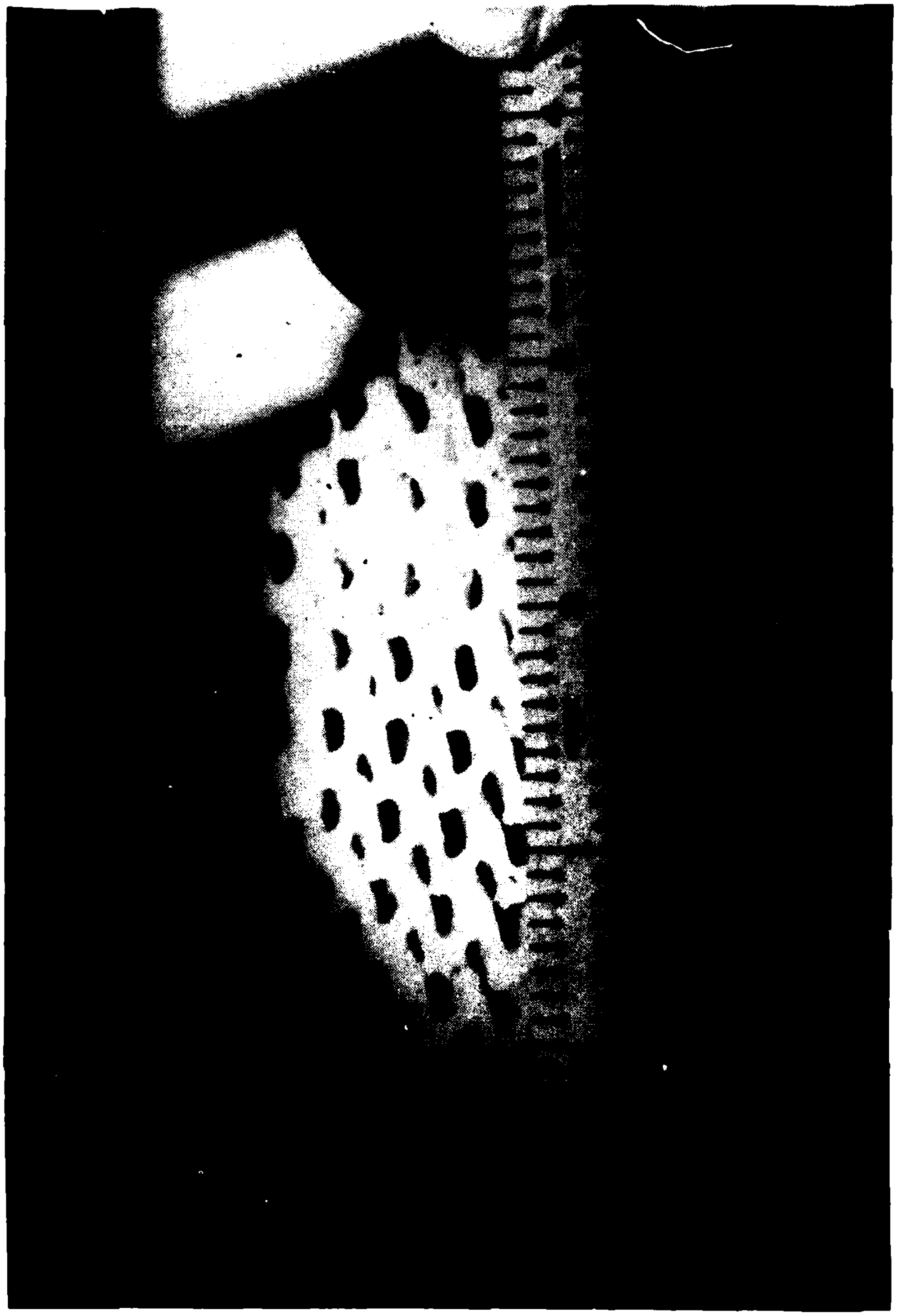


Photo 12. Natural Ice from Inlet Screens - Flight 6

Photo 13. No. 2 Engine Inlet Screen - Flight 9

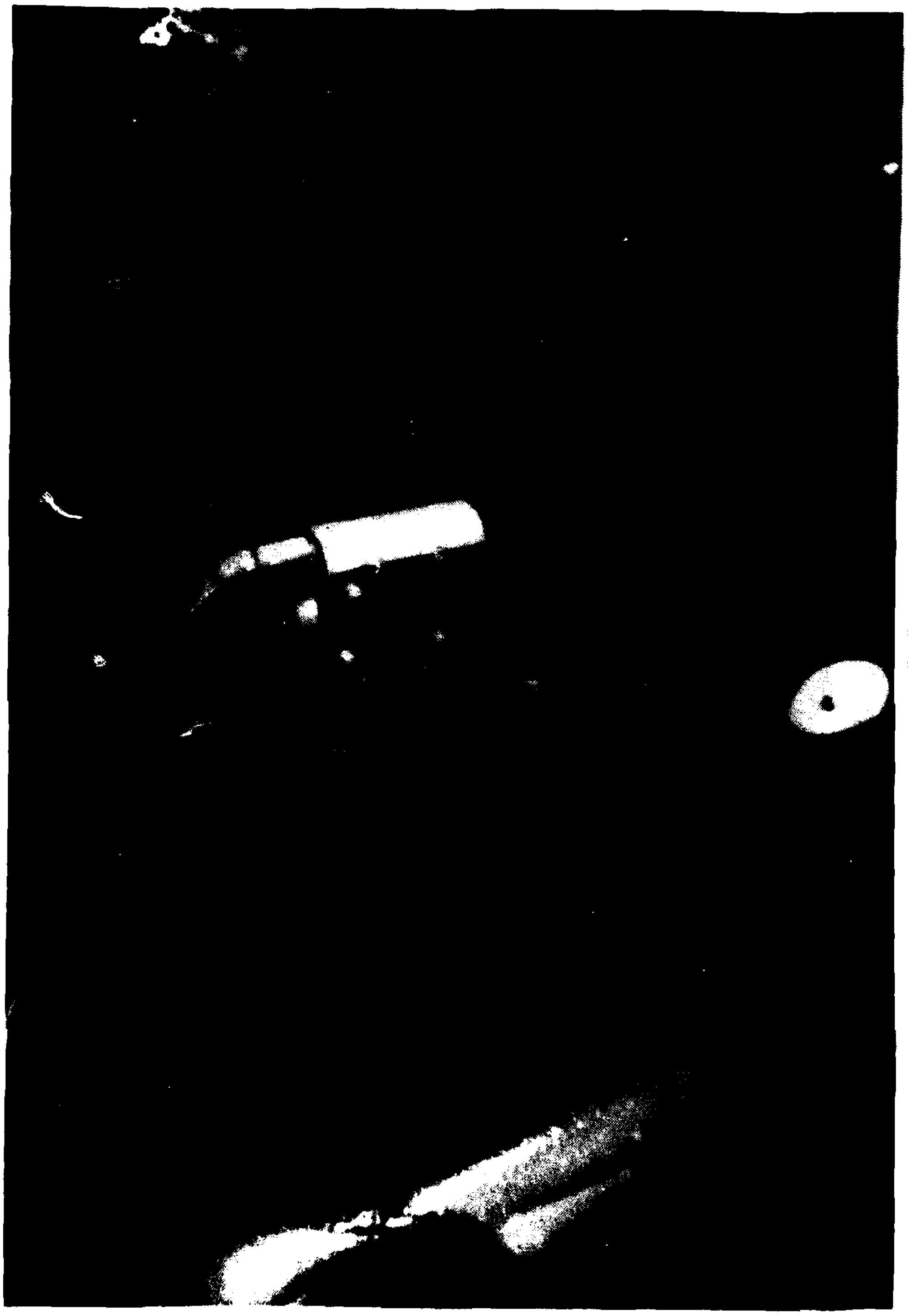


Photo 14. No. 1 Engine "D" Ring Iced - Flight 5

Photo 15. Harvey Smith Vernier Ice Detector

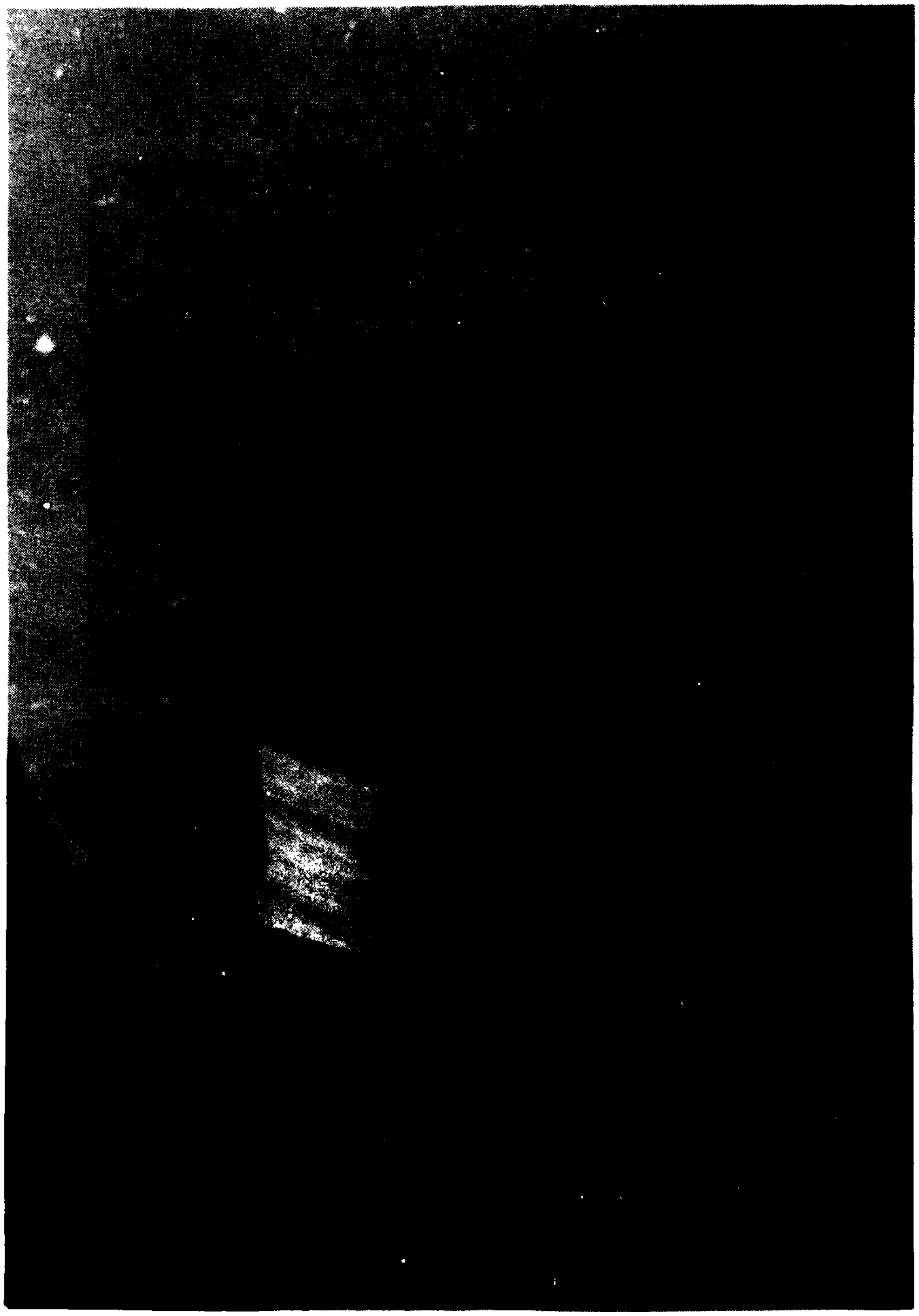


Photo 16. Free Air Temperature Probe

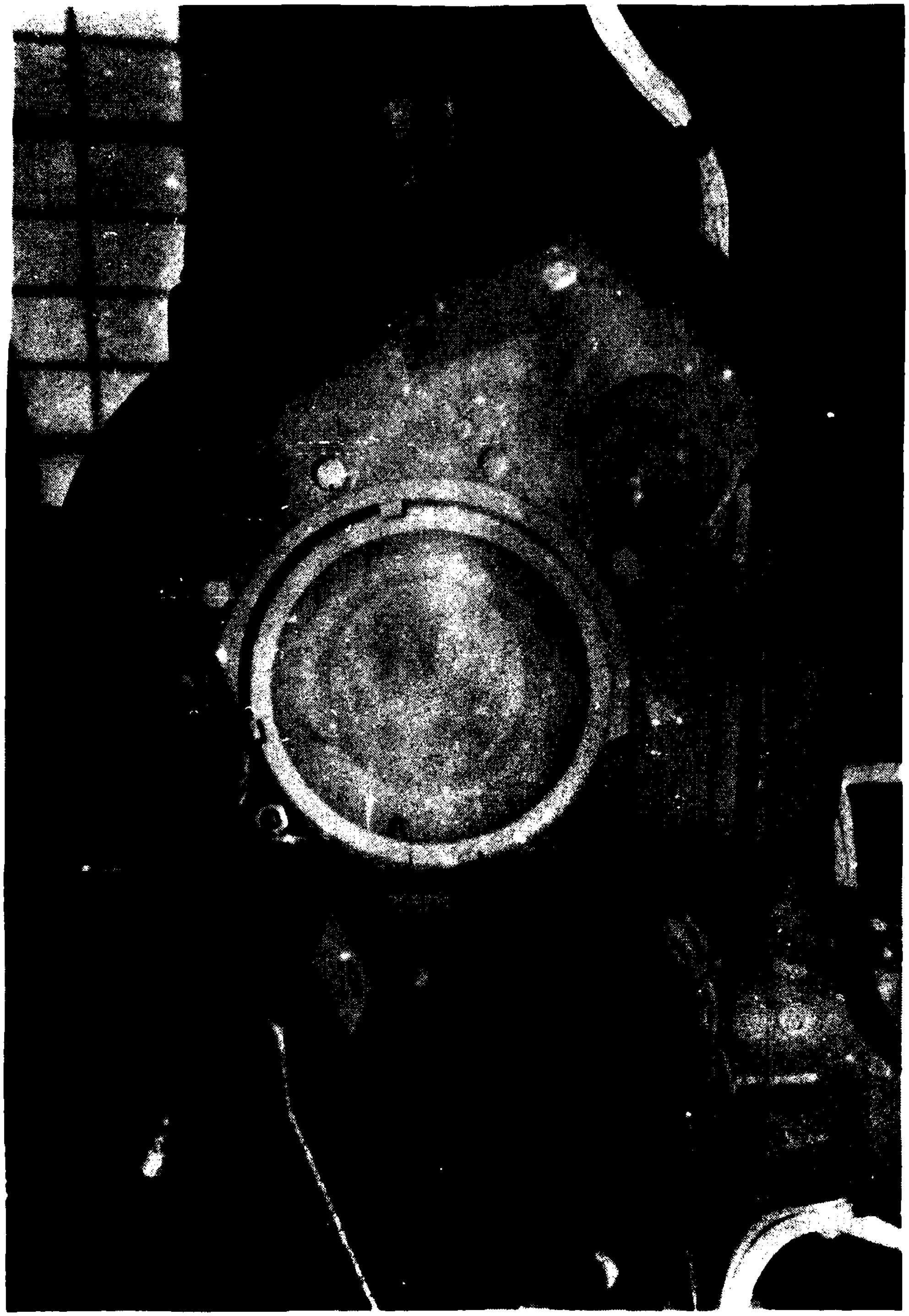


Photo 17. Aft Rotor Droop Stop Cover

Photo 18. Fuel Vent Shroud

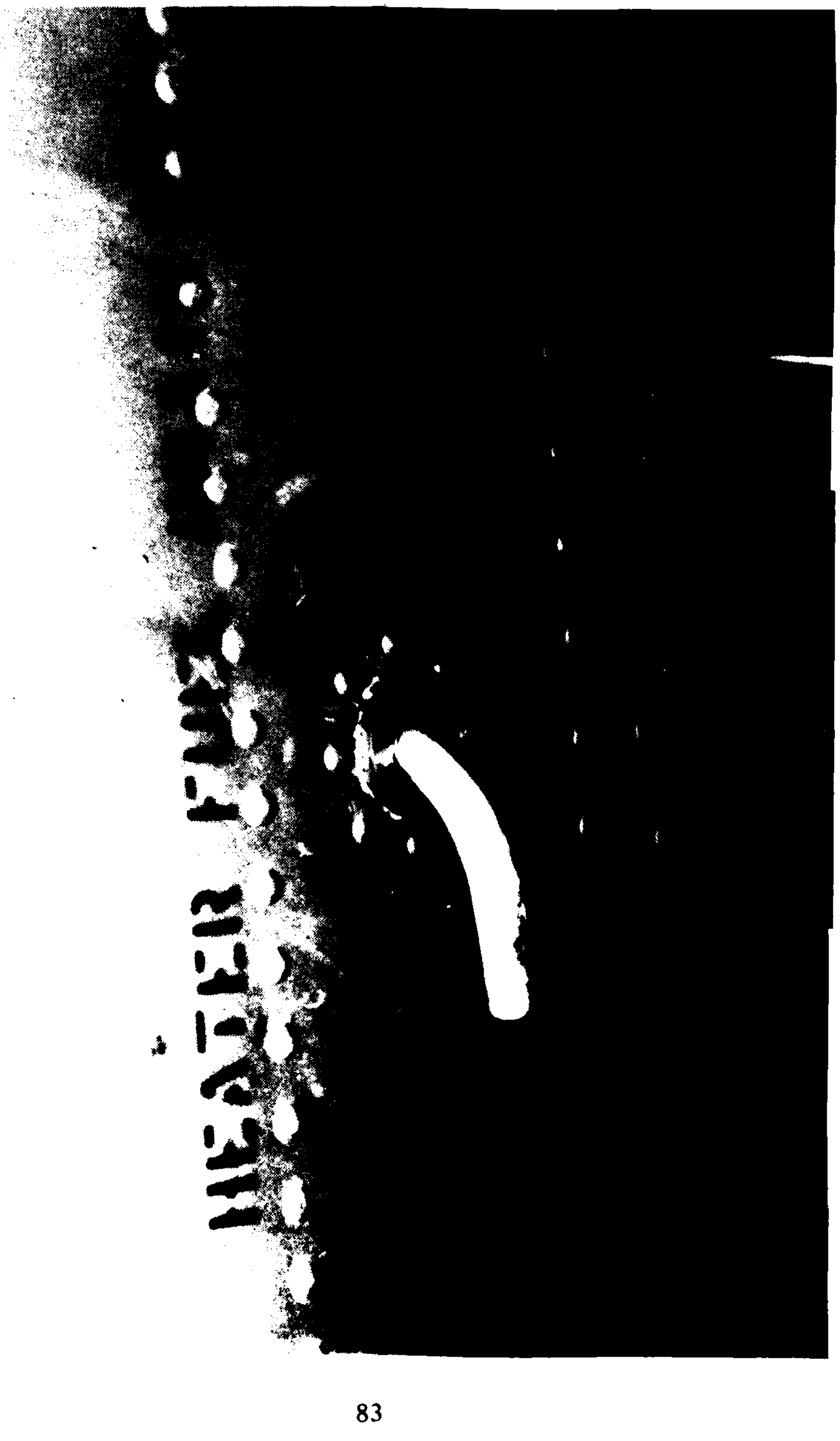


Photo 19. Modified Cabin Heater Drain

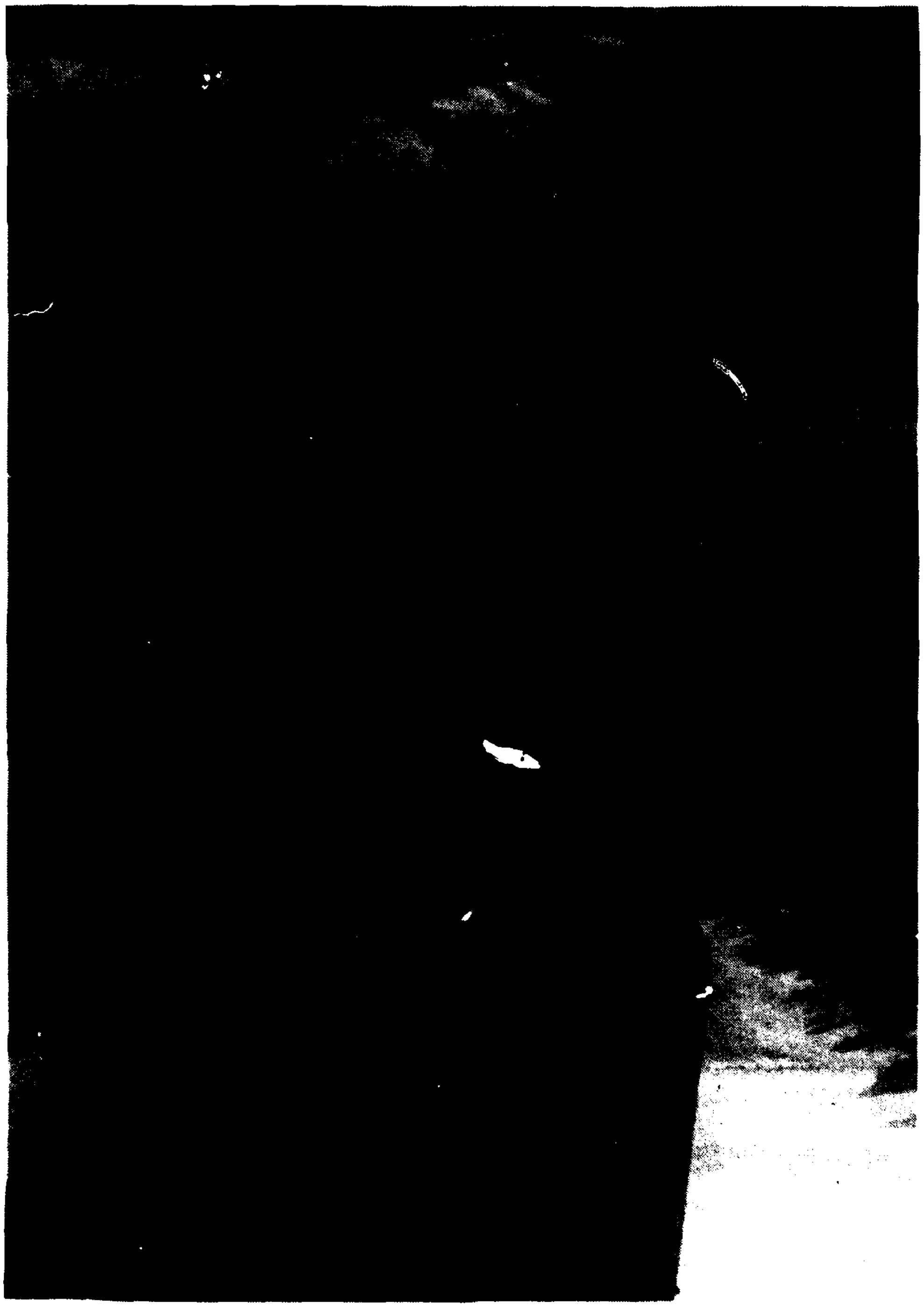


Photo 20. Oil Cooler Inlet in Aft Pylon

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